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Preliminary checklist for freshwater diatom species of the Karoo, South Africa

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Background: Species checklists are a way in which local biodiversity can be monitored. There is no readily accessible database or checklist of diatom flora of South Africa. This publication gives an account of the diatom taxa encountered during two survey projects (2010–2012 and 2015–2017) within the Eastern Karoo.

Objectives: This list has been compiled to allow for: (1) comparisons with future research in the geographical area; (2) comparison with ecological data from other countries; (3) monitoring the occurrence of new species; and (4) documentation of the disappearance of 'clean water' indicator species.

Methods: Sampling took place in the area known as the Eastern Karoo during the two projects. Samples were scrubbed, cleaned and checked for live cells. Permanent slides were made and diatoms identified using light and electron microscopy. Each species was assigned a four-letter code from the software *Omnidia* version 6.

Results: A total of 474 taxa were encountered, some of which are, as yet, undescribed. This list contains taxonomic rank currently assigned as well as the *Omnidia* codes as this software is commonly used throughout the world and in South Africa for diatom assessment protocols.

Conclusion: The National Environmental Management: Biodiversity Act does not cover the protection of diatom species, which can only realistically be conserved if the habitats in which they are found are also conserved. This species checklist can serve as a catalyst for a move towards legislation accepting the use of diatoms as bioindicators for freshwater within South Africa.

Keywords: diatoms, freshwater, bioindicator, Karoo.

Introduction

Species lists cover the occurrence of taxa in a geographical area and provides an overview of biodiversity in an area as well as a benchmark for environmental decision-making. Information of species occurring on such a list needs to be traceable (Garnett et al. 2020). Occurring in every aquatic and moist habitat, diatoms are living representatives of the environmental conditions of the habitat in which they are found. These single-celled organisms (Bacillariophyceae) are found together in associations that can be considered indicators of a particular type of water body (Schoeman 1976).

In South Africa, diatoms have been tested as bioindicators of water quality (Taylor 2004; De la Rey 2008; Matlala et al. 2008; Holmes & Taylor 2015; Pelser 2015; Musa & Greenfield 2018; Cameron 2019; Mangadze et al. 2019; Joubert 2021; Holmes et al. 2022). Diatoms, with their robust silica cell walls, have been successfully used in forensic analysis (Scott et al. 2014; Piegari et al. 2019) and historical assessments of water quality (Barker 1992; Dixit et al. 1992; Otu et al. 2011; Gordon et al. 2012; Schmidt et al. 2017). Successful application of bioindicators requires that they be correctly identified. It is for this reason that a checklist of species recorded during two projects within the Eastern Karoo area has been compiled.

The correct identification of diatoms is often perceived to be difficult (Taylor et al. 2007a). While the processing of samples as well as the identification thereof requires light microscopy, it is not impossible for this to be done by trained observers. The datasets from which this article is produced were processed on a farm in the Karoo where a laboratory was set up with a limited budget. Identification and enumeration for both datasets were done using an entry level phase contrast light microscope. Confirmation of the identification of those cells with uncertain identification was done with high resolution microscopes at either North-West University (Potchefstroom) or Nelson Mandela University (South Campus). This demonstrates that the use of diatoms as bioindicators is not limited to only those with access to university or research institution facilities.

In 2009, diatoms were included as biomonitoring organisms in the Rapid Habitat Assessment Method Manual (Department of Water Affairs and Forestry) and in 2012 they were included in the draft Rapid Ecological Reserve Assessment. The River Eco-status Monitoring Programme (REMP) replaced the River Health Programme (RHP) in 2016 and currently forms part of the National Aquatic Ecosystem Health Monitoring Programme (Department of Water and Sanitation 2016). This programme, as did its predecessor, uses only fish, invertebrates and riparian conditions to assess ecosystem health. However, in 2017, diatoms were included in the report pertaining to the development of operational procedures for the monitoring of rivers (Department of Water and Sanitation).

Although diatoms are not routinely included, they were included in several Determination of Water Resource reports (Department of Water and Sanitation 2022a, 2022b). Unfortunately, in the Karoo, fish are rarely found and, due to the extreme cold in the Karoo, insects often only occur in the summer months. It would therefore be beneficial if diatoms (occurring all year round) become part of the monitoring programme.

Red Data Species Lists classify species according to their risk of extinction and highlight areas that require conservation. While Red Data Species Lists exist for fauna and terrestrial flora in South Africa, there is no such list for diatoms. The diatom Red Data List currently in use was developed for European conditions (Cantonati et al. 2022).

The objective of this paper was to compile a preliminary checklist of diatom species from the Eastern Karoo and to highlight species found on the Red Data List. An attempt was made to include older species lists (Archibald 1983; Bate et al. 2004; Janse van Vuuren & Taylor 2015; Roussouw et al. 2018) but none of these documents have been digitised and given that there was no uniform method of reporting the species lists within the Karoo, it will be a mammoth undertaking to collate a complete list. The species list from Bate et al. (2004) has not yet been found but the permanent slides are available for perusal.

Materials and methods

Sampling took place in the area known as the Eastern Karoo (Figure 1) during the two projects. The first project included the upper reaches of the Great Fish River (spring-fed, Holmes & Taylor 2015) while the second project took place within the whole area shown in Figure 1 covering both stream and reservoir sites during the period 2015 to 2017 (Holmes et al. 2022, 2023). This semi-arid area is reliant on underground water (often stored in reservoirs above ground) and, mostly intermittent, springs. The area has extremes in weather between the winter (down to -8°C) and summer months (> 40°C) (pers. obs., M. Holmes).

Reservoirs are filled with underground water either by windmill or solar pumps. The water in these reservoirs is stored for future use and water turnover rates vary depending on water use. In the case of the reservoirs, samples were taken from the reservoir wall (usually cement substrate), unglazed ceramic tiles (placed in the reservoir after the first sampling and used as a comparison substrate for subsequent samples) and then at random sites from the plastic floatation devices from which the tiles were suspended.

Springs have a shallow water environment (1 cm to 30 cm depth) that relies completely on rain and underground water sources for recharge. Samples were scrubbed from cobbles and pebbles within riffles, using a well-cleaned toothbrush (Taylor et al. 2007b). One toothbrush per sample was used and upon returning to the laboratory, was well cleaned with detergent and water. Random samples of aquatic plants having epiphytic diatoms were taken for comparison. Samples were checked (using light microscopy) for the percentage of live cells, with chloroplasts in the cells.

Diatom samples were processed using acid digestion with the hot $KMnO_4$ and HCl method (Taylor et al. 2007b). Permanent slides were mounted using *Pleurax*. All wet material and permanent slides are held on the farm Clifton.

Identification was done using a Nikon E100 phase contrast microscope with an Olympus 100×/1.30 N.A. phase contrast objective and a Nikon 100×/1.25 N.A.

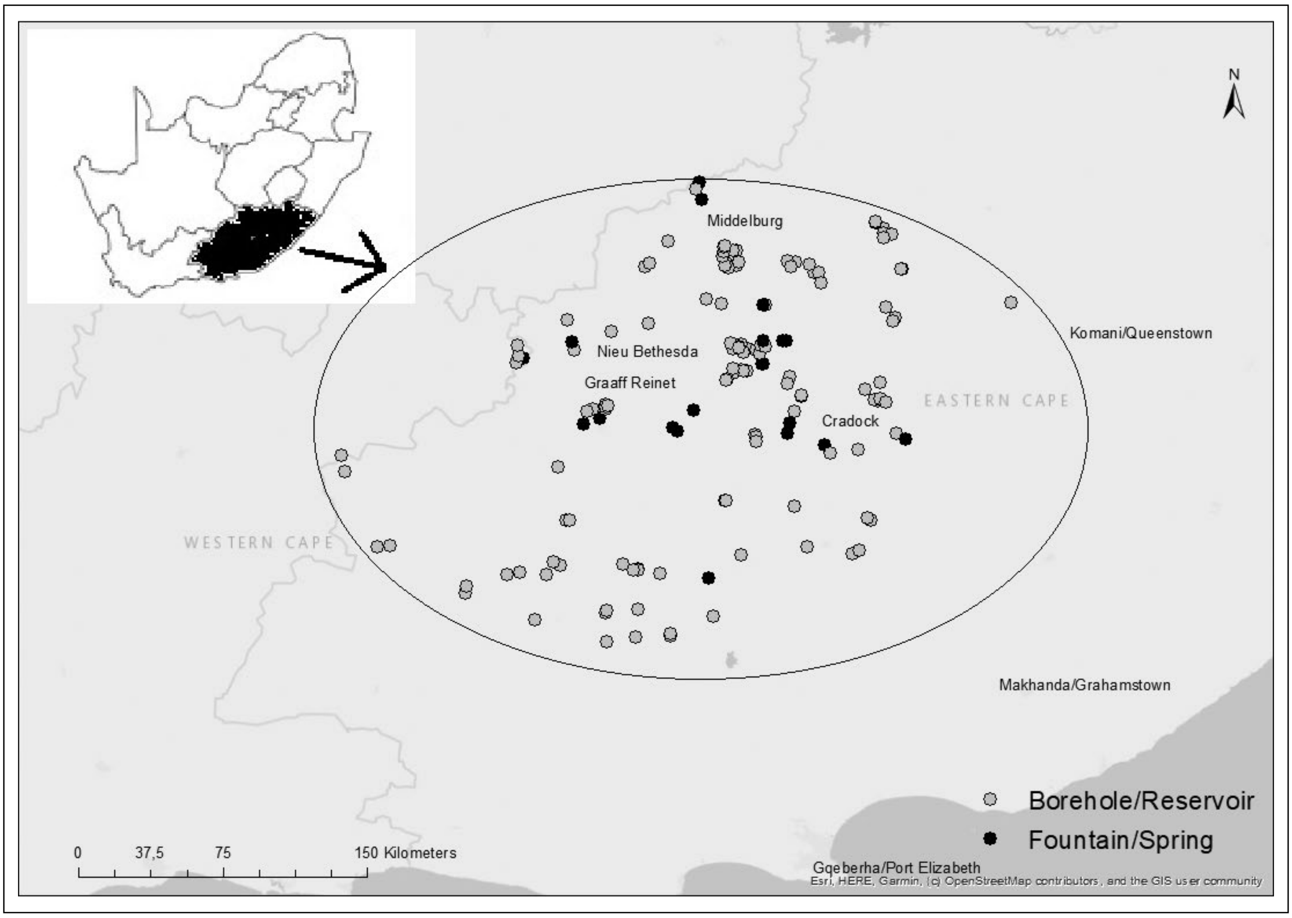

Figure 1. Sample sites (inside circle) within the Eastern Karoo from which the diatom species were identified.

phase objective. Photomicrographs were taken with a 1/2.5-Inch 5Mp CMOS Digital Image Sensor using the software IC Measure (The Imaging Software Company). At Nelson Mandela University an Olympus BX51 microscope with differential interference contrast (100x 13 N.A.) was used. Photographs and measurements of cells were taken with the mounted camera and *analySIS* image processing software. Scanning electron microscopy was done at the Centre for High Resolution Transmission Electron Microscopy (CHRTEM) at the Nelson Mandela University using a JEOL JSM7001F scanning electron microscope. Cleaned samples were placed on an isopore 0.2 μm pore-size membrane (Millipore™) filter precoated with gold. Once dried, the samples were attached to an aluminium stub with carbon conductive double-sided tape and sputter coated with gold at 25 mA for 30 seconds. Imaging was done at an accelerating voltage of 3 kV.

Each species was assigned a four-letter code from the software *Omnidia* version 6 (Lecointe et al. 1993, 1999, 2016). *Omnidia* (v6) was used to compile the species lists from the projects. For species that could only be identified to genus level, a unique code was assigned to each species while for those that could not be identified to a genus level, the code ZZZZ was assigned. Although environmental preferences for cosmopolitan diatoms can vary, there are some species that are always considered pollution sensitive. As pristine conditions decline, some of these diatom species have been placed on Red Data Lists. Species occurring on the two most recent Red Data Lists for diatoms in Europe were accessed (Rote Liste Zentrum 2018; Täuscher 2020).

Results

A table with an alphabetical list – including the four-letter *Omnidia* codes – of the diatoms identified in the Eastern Karoo is given in Table 1. The list of species only identified to genus-level or above can be requested from the corresponding author (with images, file size >50 MB).

A total of 474 taxa were recorded from 607 samples (n = 101 from 2010 to 2012 and n = 506 from 2015 to 2017). Several species that could not be identified to genus level were given the code ZZZZ. The species in this grouping (ZZZZ) that were of the same morphological 'taxa' were grouped together (n = 48 'taxa'). Several species previously misidentified are now placed in different groupings and listed in Table 2. *Amphora* sp0 was found to have a range of morphological variation within the same sample (Figure 2, Table 2).

Table 1. Preliminary diatom species list for the Eastern Karoo with the *Omnidia* (v6) codes. Species with * are on the Red List (Täuscher 2020) and + indicates inclusion in the 2018 list (Rote Liste Zentrum). Species in bold occurred with a relative abundance >10% in at least one sample. When names have changed, the new names are provided alongside their synonyms. These changes were verified through AlgaeBase as on 31 October 2024

Taxa	Omnidia Code
Cells not identified to genus level	**ZZZZ**
Deformed diatom cells	DEFO
***Achnanthes brevipes* C.Agardh**	**ABRE**
Achnanthes brevipes var. *angustata* (Greville) Cleve	ABAN
Achnanthes brevipes var. *intermedia* (Kützing) Cleve	ABIN
Achnanthes coarctata (Brébisson) Grunow	ACOA
Achnanthes spp.	ACHS
Achnanthidium affine (Grunow) Czarnecki	ACAF
Achnanthidium atomoides Monnier, Lange-Bertalot & Ector	ADAM
Achnanthidium caledonicum (Lange-Bertalot) Lange-Bertalot	ADCA
Achnanthidium catenatum (Bily & Marvan) Lange-Bertalot	ADCT
Achnanthidium crassum (Hustedt) Potapova & Ponader	ADCR
***Achnanthidium eutrophilum* (Lange-Bertalot) Lange-Bertalot**	**ADEU**
Achnanthidium exile (Kützing) Heiberg	ADEX
Achnanthidium gracillimum (F.Meister) Lange-Bertalot	ADGL
***Achnanthidium jackii* Rabenhorst**	**ADJK**
Achnanthidium macrocephalum (Hustedt) Round & Bukhtiyarova	ADMA
Achnanthidium microcephalum Kützing	ADMC
***Achnanthidium minutissimum* (Kützing) Czarnecki**	**ADMI**
Achnanthidium neomicrocephalum Lange-Bertalot & Staab	ADNM
Achnanthidium pyrenaicum (Hustedt) H.Kobayasi	ADPY
Achnanthidium rivulare Potapova & Ponader	ADRI
***Achnanthidium saprophilum* (H.Kobayasi & Mayama) Round & Bukhtiyarova**	**ADSA**
***Achnanthidium* spp.**	**ACHD**
Achnanthidium straubianum (Lange-Bertalot) Lange-Bertalot	ADSB
*+*Achnanthidium subatomus* (Hustedt) Lange-Bertalot	ADSU
***Adlafia bryophila* (Petersen) Lange-Bertalot**	**ABRY**
Adlafia minuscula (Grunow) Lange-Bertalot	ADMS
Adlafia spp.	ADSP
Amphipleura pellucida (Kützing) Kützing	APEL
Amphora copulata (Kützing) Schoeman & R.E.M.Archibald	ACOP
Amphora inariensis Krammer	AINA
Amphora ovalis (Kützing) Kützing	AOVA
***Amphora pediculus* (Kützing) Grunow**	**APED**
***Amphora* spp.**	**AMPS**
Aneumastus spp.	ANES
Anomoeoneis sp.	ANOS

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Taxa	Omnidia Code
Anomoeoneis sphaerophora (Ehrenberg) Pfitzer	ASPH
Aulacoseira distans (Ehrenberg) Simonsen	AUDI
Aulacoseira granulata (Ehrenberg) Simonsen	AUGR
***Aulacoseira granulata* (Ehrenberg) Simonsen var. *angustissima* (O.Müller) Simonsen**	**AUGA**
Aulacoseira pusilla (F.Meister) A.Tuji & A.Houki	AUPU
Aulacoseira sp.	AULS
Bacillaria paxillifera (O.F.Müller) T.Marsson	BPAX
SYN *Bacillaria paradoxa* Gmelin	BPAR
Brachysira calcicola Lange-Bertalot	BCAL
+*Brachysira liliana* Lange-Bertalot	BLIL
***Brachysira* sp. (*B. neoexilis*) shape**	**BNEO**
***Brachysira* spp.**	**BRCS**
Caloneis sp.	CALO
Caloneis bacillum (Grunow) Cleve	CBAC
Caloneis molaris (Grunow) Krammer	CMOL
Caloneis tenuis (W.Gregory) Krammer	CATE
***Chaetoceros* sp.**	**CHTS**
Chamaepinnularia spp.	CHSP
Cocconeis sp.	COCO
***Cocconeis engelbrechtii* Cholnoky**	**CENG**
***Cocconeis lineata* Ehrenberg**	**CLNT**
SYN *Cocconeis placentula* var. *lineata* (Ehrenberg) Van Heurck	**CPLI**
***Cocconeis pediculus* Ehrenberg**	**CPED**
***Cocconeis placentula* Ehrenberg**	**CPLA**
***Cocconeis euglypta* Ehrenberg**	**CEUG**
SYN *Cocconeis placentula* var. *euglypta* (Ehrenberg) Cleve	**CPLE**
Conticribra weissflogii (Grunow) Stachura-Suchoples & D.M.Williams	CTWE
SYN *Thalassiosira weissflogii* (Grunow) G.A.Fryxell & Hasle	TWEI
Craticula accomoda (Hustedt) D.G.Mann	CRAC
Craticula accomodiformis Lange-Bertalot	CACM
Craticula ambigua (Ehrenberg) D.G.Mann	CAMB
***Craticula* cf. *buderi* (Hustedt) Lange-Bertalot**	**CRBU**
Craticula elkab (O.Müller ex O.Müller) Lange-Bertalot, Kusber & Cocquyt	CREK
Craticula halophila (Grunow) D.G.Mann	CHAL
Craticula molestiformis (Hustedt) Mayama	CMFO
cf. *Craticula simplex* (Krasske) Levkov	**CRSI**
***Craticula* spp.**	**CRTS**

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Taxa	Omnidia Code
***Craticula subminuscula* (Manguin) C.E.Wetzel & Ector**	**CSNU**
Craticula vixnegligenda Lange-Bertalot	CVIX
Craticula zizix (VanLandingham) Guiry	CZIZ
SYN Craticula molesta Lange-Bertalot & Willmann	CRML
Cyclostephanos dubius (Hustedt) Round	CDUB
Cyclostephanos invisitatus (M.H.Hohn & Hellerman) E.C.Theriot, Stoermer & Håkansson	CINV
Cyclostephanos sp.	CYCS
***Cyclotella atomus* Hustedt**	**CATO**
Cyclotella atomus var. *gracilis* Genkal & Kiss	CAGR
Cyclotella meduanae H.Germain	CMED
Cyclotella spp.	CYCL
Cymbella affiniformis Krammer	CAFM
Cymbella bengalensis Grunow	CBEN
*+*Cymbella cymbiformis* C.Agardh	CCYM
Cymbella dorsenotata Østrup	CDNO
***Cymbella kappii* (Cholnoky) Cholnoky**	**CKPP**
Cymbella kolbei Hustedt	CKOL
***Cymbella neocistula* Krammer**	**CNCI**
***Cymbella percymbiformis* Krammer**	**CPCF**
Cymbella simonsenii Krammer	CSMO
Cymbella spp.	CYMB
Cymbella tumida (Brébisson) Van Heurck	CTUM
Cymbella zambesiana Krammer	CZAM
***Denticula kuetzingii* Grunow**	**DKUE**
***Denticula kuetzingii* var. *rumrichae* Krammer**	**DKRU**
***Denticula* spp.**	**DENS**
Denticula subtilis Grunow	DSUB
Diadesmis confervacea Kützing	DCOF
***Diatoma vulgaris* Bory**	**DVUL**
Diploneis puella (Schumann) Cleve	DPUE
Diploneis smithii (Brébisson) Cleve	DSMI
***Diploneis* sp. previously identified as *D. elliptica* (Kützing) Cleve**	**DIPS0**
Diploneis spp.	DIPS
Diploneis subovalis Cleve	DSBO
***Discostella pseudostelligera* (Hustedt) Houk & Klee**	**DPSG**
Discostella stelligera (Cleve & Grunow) Houk & Klee	DSTE
Encyonema cespitosum Kützing	ECAE

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Taxa	Omnidia Code
*Encyonema minutum (*Hilse) D.G.Mann	ENMI
Encyonema silesiacum (Bleisch) D.G.Mann	ELSE
Encyonema volkii (U.Rumrich, Krammer & Lange-Bertalot) Krammer	EVOL
Encyonopsis buedelii Krammer	ECBU
***+*Encyonopsis cesatii* (Rabenhorst) Krammer**	**ECES**
***Encyonopsis* cf. *cesatiformis* Krammer**	**ECCF**
***Encyonopsis krammeri* E.Reichardt**	**ECKR**
Encyonopsis krammerioides Lange-Bertalot & U.Rumrich	EKMD
***Encyonopsis microcephala* (Grunow) Krammer**	**ENCM**
***Encyonopsis minuta* Krammer & E.Reichardt**	**ECPM**
***Encyonopsis* spp.**	**ECNS**
***Encyonopsis subminuta* Krammer & E.Reichardt**	**ESUM**
Encyonopsis thumensis Krammer	ETHU
***Entomoneis paludosa* (W.Smith) Reimer**	**EPAL**
***Epithemia adnata* (Kützing) Brébisson**	**EADN**
***Epithemia gibba* (Ehrenberg) Kützing**	**EGBA**
SYN *Rhopalodia gibba* (Ehrenberg) O.Müller	**RGIB**
***Epithemia operculata* (C.Agardh) Ruck & Nakov**	**EOPE**
SYN *Rhopalodia operculata* (C.Agardh) Håkansson	**ROPE**
***Epithemia sorex* Kützing**	**ESOR**
Epithemia spp.	EPIS1
Epithemia turgida (Ehrenberg) Kützing	EELG
SYN *Cymbella turgida* W.Gregory	CTUR
Eunotia sp.	EUNO
Fallacia pygmaea (Kützing) Stickle & D.G.Mann	FPYG
Fallacia sp.	FALS
Fallacia tenera (Hustedt) D.G.Mann	FTNR
Fistulifera pelliculosa (Kützing) Lange-Bertalot	FPEL
Fragilaria capucina Desmazieres	FCAP
***Fragilaria vaucheriae* (Kützing) J.B.Petersen**	**FVAU**
SYN *Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot	**FCVA**
Fragilaria crotonensis Kitton	FCRO
Fragilaria pararumpens Lange-Bertalot, G.Hofmann & Werum	FPRU
Fragilaria radians (Kützing) D.M.Williams & Round	FRAD
SYN *Fragilaria gracilis* Østrup	FGRA
Fragilaria rumpens (Kützing) G.W.F.Carlson	FRUM
SYN *Fragilaria capucina* subsp. *rumpens* (Kützing) Lange-Bertalot	FCRP

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Taxa	Omnidia Code
***Fragilaria* spp.**	**FRAS**
***Fragilaria tenera* (W.Smith) Lange-Bertalot**	**FTEN**
***Fragilaria tenera* var. *nanana* (Lange-Bertalot) Lange-Bertalot & S.Ulrich**	**FTNA**
SYN *Fragilaria nanana* Lange-Bertalot	**FNAN**
Frustulia vulgaris (Thwaites) De Toni	FVUL
Frustulia sp.	FRUS
***Gogorevia exilis* (Kützing) Kulikovskiy & Kociolek**	**GGEX**
SYN *Achnanthidium exiguum* (Grunow) Czarnecki	**ADEG**
Gomphonema acuminatum Ehrenberg	GACU
Gomphonema affine Kützing	GAFF
Gomphonema affine var. *insigne* (W.Gregory) G.W.Andrews	GAFI
Gomphonema angustatum (Kützing) Rabenhorst	GANG
*+*Gomphonema auritum* A.Braun ex Kützing	GAUR
Gomphonema clavatulum E.Reichardt	GCVT
*+*Gomphonema exilissimum* (Grunow) Lange-Bertalot & E.Reichardt	GEXL
***Gomphonema gracile* Ehrenberg**	**GGRA**
*+*Gomphonema insigne* W.Gregory	GINS
Gomphonema italicum Kützing	GITA
Gomphonema lagenula Kützing	GLGN
Gomphonema laticollum E.Reichardt	GLTC
Gomphonema minutum (C.Agardh) C.Agardh	GMIN
***Gomphonema parvulum* (Kützing) Kützing**	**GPAR**
Gomphonema pseudoaugur Lange-Bertalot	GPSA
Gomphonema pumilum (Grunow) E.Reichardt & Lange-Bertalot	GPUM
Gomphonema pumilum var. *rigidum* E.Reichardt & Lange-Bertalot	GPRI
Gomphonema spp.	GOMP
Gomphonema spiculoides H.P.Gandhi	GSPI
Gomphonema subclavatum (Grunow) Grunow	GSCL
Gomphonema venustum S.I.Passy, Kociolek & R.C.Lowe	GVNU
Gyrosigma acuminatum (Kützing) Rabenhorst	GYAC
Gyrosigma rautenbachiae Cholnoky	GRAU
Gyrosigma scalproides (Rabenhorst) Cleve	GSCA
Halamphora coffeiformis (C.Agardh) Mereschkowsky	HACO
Halamphora montana Krasske (Levkov)	HLMO
Halamphora oligotraphenta (Lange-Bertalot) Levkov	HOLI
Halamphora sp.	HALS
***Halamphora veneta* (Kützing) Levkov**	**HVEN**

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Taxa	Omnidia Code
Hantzschia amphioxys (Ehrenberg) Grunow	HAMP
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	HCAP
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski	HHUN
Hippodonta spp.	HIPO1
Lemnicola hungarica (Grunow) Round & Basson	LHUN
Luticola mutica (Kützing) D.G.Mann	LMUT
Luticola nivalis (Ehrenberg) D.G.Mann	LNIV
Mastogloia dansei (Thwaites) Thwaites ex W.Smith	MDAN
Mastogloia elliptica (C.Agardh) Cleve	MELL
Mayamaea atomus (Kützing) Lange-Bertalot	MAAT
***Mayamaea permitis* (Hustedt) Bruder & Medlin**	**MPMI**
Melosira varians C.Agardh	MVAR
Microcostatus Johansen & Sray	MCCT
Navicula amphiceropsis Lange-Bertalot & U.Rumrich	NAAM
**Navicula angusta* Grunow	NAAN
Navicula antonii Lange-Bertalot	NANT
Navicula arvensis var. *dubia* Lange-Bertalot	NARM
SYN *Navicula arvensis* var. *major* Lange-Bertalot	NAMA
***Navicula capitatoradiata* H.Germain ex Gasse**	**NCPR**
Navicula cincta (Ehrenberg) Ralfs	NCIN
Navicula cryptocephala Kützing	NCRY
Navicula cryptotenella Lange-Bertalot	NCTE
Navicula cryptotenelloides Lange-Bertalot	NCTO
***Navicula erifuga* Lange-Bertalot**	**NERI**
+*Navicula exilis* Kützing	NEXI
Navicula germainii J.H.Wallace	NGER
Navicula gregaria Donkin	NGRE
Navicula libonensis Schoeman	NLIB
***Navicula metareichardtiana* Lange-Bertalot & Kusber**	**NMTA**
SYN *Navicula reichardtiana* Lange-Bertalot	**NRCH**
Navicula microcari Lange-Bertalot	NMCA
+*Navicula notha* J.H.Wallace	NNOT
***Navicula radiosa* Kützing**	**NRAD**
Navicula ranomafanensis (Manguin) Metzeltin & Lange-Bertalot	NRAN
Navicula recens (Lange-Bertalot) Lange-Bertalot	NRCS
Navicula reinhardtii (Grunow) Grunow	NREI
Navicula rhynchocephala Kützing	NRHY

Table 1. Preliminary diatom species list for the Eastern Karoo with the *Omnidia* (v6) codes. Species with * are on the Red List (Täuscher 2020) and + indicates inclusion in the 2018 list (Rote Liste Zentrum). Species in bold occurred with a relative abundance >10% in at least one sample. When names have changed, the new names are provided alongside their synonyms. These changes were verified through AlgaeBase as on 31 October 2024 (continued)

Taxa	Omnidia Code
Navicula riediana Lange-Bertalot & Rumrich	NRIE
Navicula rostellata Kützing	NROS
***Navicula salinicola* Hustedt**	**NSLC**
Navicula schroeteri F.Meister	NSHR
Navicula spp.	NAVI
Navicula subhamulata Grunow	NSBH
+*Navicula subrhynchocephala* Hustedt	NSRH
Navicula symmetrica R.M.Patrick	NSYM
Navicula tenelloides Hustedt	NTEN
Navicula tripunctata (O.F.Müller) Bory	NTPT
Navicula trivialis Lange-Bertalot	NTRV
Navicula vandamii Schoeman & R.E.M.Archibald	NVDA
Navicula vandamii var. *mertensiae* Lange-Bertalot	NVDM
***Navicula veneta* Kützing**	**NVEN**
Navicula viridula (Kützing) Ehrenberg	NVIR
Navicula zanoni Hustedt	NZAN
***Navigeia decussis* (Østrup) Bukhtiyarova**	**NGDU**
SYN *Geissleria decussis* (Østrup) Lange-Bertalot & Metzeltin	**GDEC**
*+*Neidium productum* (W.Smith) Cleve	NEPR
Neidium sp.	NEID
Nitzschia acicularis (Kützing) W.Smith	NACI
*+*Nitzschia acidoclinata* Lange-Bertalot	NACD
***Nitzschia agnewii* Cholnoky**	**NAGW**
Nitzschia agnita Hustedt	NAGN
***Nitzschia amphibia* Grunow**	**NAMP**
Nitzschia amphibia f. *frauenfeldii* (Grunow) Lange-Bertalot	NAFR
***Nitzschia archibaldii* Lange-Bertalot**	**NIAR**
Nitzschia aurariae Cholnoky	NAUR
***Nitzschia bacata* Hustedt**	**NZBA**
Nitzschia bacillum Hustedt	NBCL
Nitzschia capitellata Hustedt	NCPL
Nitzschia clausii Hantzsch	NCLA
***Nitzschia communis* Rabenhorst**	**NCOM**
Nitzschia commutata Grunow	NICO
Nitzschia desertorum Hustedt	NDES
***Nitzschia dissipata* (Kützing) Grunow**	**NDIS**
Nitzschia draveillensis Coste & Ricard	NDRA

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Taxa	Omnidia Code
***Nitzschia elegantula* Grunow**	**NELE**
Nitzschia etoshensis Cholnoky	NETO
Nitzschia filiformis (W.Smith) Van Heurck	NFIL
***Nitzschia fonticola* (Grunow) Grunow**	**NFON**
Nitzschia frequens Hustedt	NIFQ
***Nitzschia frustulum* (Kützing) Grunow**	**NIFR**
Nitzschia fruticosa Hustedt	NIFT
+ *Nitzschia gisela* Lange-Bertalot	NGIS
***Nitzschia gracilis* Hantzsch**	**NIGR**
*+ *Nitzschia hantzschiana* Rabenhorst	NHAN
Nitzschia heufleriana Grunow	NHEU
***Nitzschia inconspicua* Grunow**	**NINC**
***Nitzschia intermedia* Hantzsch ex Cleve & Grunow**	**NINT**
Nitzschia irremissa Cholnoky	NIRM
Nitzschia lancettula O.Müller	NLTL
***Nitzschia liebethruthii* Rabenhorst**	**NLBT**
***Nitzschia linearis* W.Smith**	**NLIN**
***Nitzschia linearis* var. *subtilis* Hustedt**	**NLSU**
+ *Nitzschia media Hantzsch*	NIME
SYN *Nitzschia dissipata* var. *media (Hantzsch) Grunow*	NDME
Nitzschia microcephala Grunow	NMIC
Nitzschia nana Grunow	NNAN
***Nitzschia palea* (Kützing) W.Smith**	**NPAL**
Nitzschia palea var. *debilis* (Kützing) Grunow	NPAD
Nitzschia palea var. *tenuirostris* Grunow	NPAT
***Nitzschia paleacea* (Grunow) Grunow**	**NPAE**
Nitzschia cf. *paleaeformis* Hustedt	NIPF
***Nitzschia perminuta* Grunow**	**NIPM**
Nitzschia perspicua Cholnoky	NPRP
**Nitzschia pumila* Hustedt	NPML
Nitzschia pura Hustedt	NIPR
Nitzschia pusilla Grunow	NIPU
+*Nitzschia radicula* Hustedt	NZRA
Nitzschia rautenbachiae Cholnoky	NRTB
Nitzschia recta Hantzsch	NREC
+*Nitzschia regula* Hustedt	NIRE
Nitzschia reversa W.Smith	NREV

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Taxa	Omnidia Code
Nitzschia rosenstockii Lange-Bertalot	NRST
Nitzschia scalpelliformis (Grunow) Grunow	NISC
Nitzschia semirobusta Lange-Bertalot	NSRB
Nitzschia sigma (Kützing) W.Smith	NSIG
Nitzschia sigmoidea (Nitzsch) W.Smith	NSIO
Nitzschia siliqua R.E.M.Archibald	NSLQ
***Nitzschia sociabilis* Hustedt**	**NSOC**
Nitzschia solita Hustedt	NISO
Nitzschia spp.	NZSS
***Nitzschia* cf. *spiculoides* Hustedt**	**NSLO**
Nitzschia spiculum Hustedt	NISP
Nitzschia subacicularis Hustedt	NSUA
***Nitzschia* cf. *subsalsa* Cholnoky**	**NSSA**
Nitzschia subtilis (Kützing) Grunow	NISU
***Nitzschia supralitorea* Lange-Bertalot**	**NZSU**
***Nitzschia tropica* Hustedt**	**NTRO**
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	NUMB
*+*Nitzschia valdecostata* Lange-Bertalot & Simonsen	NVLC
Nitzschia vildaryana U.Rumrich & Lange-Bertalot	NVDR
+*Pinnularia bertrandii* var. *angustefasciata* Krammer	PBEA
Pinnularia borealis Ehrenberg	PBOR
**Pinnularia brebissonii* (Kützing) Rabenhorst	PBRE
+*Pinnularia divergens* W.Smith	PDIV
+*Pinnularia microstauron* (Ehrenberg) Cleve	PMIC
Pinnularia microstauron var. *rostrata* Krammer	PMRO
Pinnularia spp.	PINS
Pinnularia subbrevistriata Krammer	PSBV
Pinnularia subcapitata W.Gregory	PSCA
Placoneis dicephala (Ehrenberg) Mereschkowsky	PDIC
Placoneis elginensis (W.Gregory) E.J.Cox	PELG
Placoneis sp.	PLAC
Planothidium delicatulum (Kützing) Round & Bukhtiyarova	PTDE
Planothidium engelbrechtii (Cholnoky) Round & Bukhtiyarova	PLEN
***Planothidium frequentissimum* (Lange-Bertalot) Lange-Bertalot**	**PLFR**
***Planothidium lanceolatum* (Brébisson ex Kützing) Lange-Bertalot**	**PTLA**
Planothidium rostratum (Østrup) Round & Bukhtiyarova	PRST
Planothidium sp. Round & Bukhtiyarova	PTDS

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Taxa	Omnidia Code
Platessa oblongella (Østrup) C.E.Wetzel, Lange-Bertalot & Ector	POBL
Pleurosigma salinarum (Grunow) Cleve & Grunow	PSAL
Pseudofallacia monoculata (Hustedt) Y.Liu, Kociolek & Q.Wang	PMOC
SYN *Fallacia monoculata* (Hustedt) D.G.Mann	FMOC
***Pseudostaurosira brevistriata* (Grunow) Williams & Round**	**PSBR**
***Pseudostaurosira elliptica* (Schumann) Edlund, Morales & Spaulding**	**PSSE**
SYN *Staurosira elliptica* (Schumann) Williams & Round	**SELI**
***Pseudostaurosira subsalina* (Hustedt) Morales**	**PSSB**
Reimeria sinuata (W.Gregory) Kociolek & Stoermer	RSIN
***Rhoicosphenia abbreviata* (C.Agardh) Lange-Bertalot**	**RABB**
Rhopalodia gibberula (Ehrenberg) O.Müller	RGBL
Rhopalodia sp.	RHOS
Sellaphora bacilloides (Hustedt) Levkov, Krstic & Nakov	SBLO
***Sellaphora nigri* (De Notaris) Wetzel & Ector**	**SNIG**
SYN *Eolimna minima* (Grunow) Lange-Bertalot	**EOMI**
Sellaphora pupula (Kützing) Mereschkowsky	SPUP
Sellaphora seminulum (Grunow) D.G.Mann	SSEM
+***Sellaphora stroemii* (Hustedt) H.Kobayasi**	**SSTM**
***Seminavis pusilla* (Grunow) E.J.Cox & G.Reid**	**SMPU**
SYN *Navicymbula pusilla* (Grunow) Krammer	**NCPU**
Simonsenia delognei Lange-Bertalot	SIDE
Stauroneis sp.	STAU
Stauroneis smithii Grunow	SSMI
***Staurosira construens* Ehrenberg**	**SCON**
Staurosira sp.	SSPE
***Staurosira venter* (Ehrenberg) Cleve & J.D.Möller**	**SSVE**
SYN *Staurosira construens* var. *venter* (Ehrenberg) Hamilton	**SCVE**
***Staurosirella pinnata* (Ehrenberg) Williams & Round**	**SPIN**
Stephanocyclus cryptica (Reimann, Levin & Guillard) Kulikovskiy, Genkal & Kociolek	SCCR
SYN *Cyclotella cryptica* Reimann, Lewin & Guillard	CCRY
***Stephanocyclus meneghiniana* (Kützing) Kulikovskiy, Genkal & Kociolek**	**SCME**
SYN *Cyclotella meneghiniana Kützing*	**CMEN**
Stephanodiscus agassizensis Håkansson & Kling	SAGA
Stephanodiscus hantzschii Grunow	SHAN
Stephanodiscus minutulus (Kützing) Cleve & Moller	STMI
Surirella angusta Kützing	SANG
Surirella brebissonii Krammer & Lange-Bertalot	SBRE

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Taxa	Omnidia Code
Surirella librile Ehrenberg	SULI
SYN *Cymatopleura solea* (Brébisson) W.Smith	CSOL
Surirella microlibrile Van de Vijver, Pottiez & Jüttner	SMLI
SYN *Cymatopleura solea* var. *apiculata* (W. Smith) Ralfs	CSAP
Surirella ostentata Cholnoky	SUOS
Surirella ovalis Brébisson	SOVI
***Tabularia fasciculata* (C.Agardh) Williams & Round**	**TFAS**
***Tryblionella angustata* W.Smith**	**TANG**
SYN *Nitzschia angustata* (W.Smith) Grunow	**NIAN**
Tryblionella angustatula (Lange-Bertalot) Cantonati & Lange-Bertalot	**TATU**
SYN *Nitzschia angustatula* Lange-Bertalot	**NZAG**
***Tryblionella apiculata* W.Gregory**	**TAPI**
Tryblionella calida (Grunow) D.G.Mann	TCAL
Tryblionella debilis Arnott	TDEB
Tryblionella gracilis W.Smith	TGRL
Tryblionella hungarica (Grunow) D.G.Mann	THUN
Tryblionella levidensis W.Smith	TLEV
Tryblionella littoralis (Grunow) D.G.Mann	TLIT
Tryblionella sp.	TRYB
***Ulnaria acus* (Kützing) Aboal**	**UACU**
***Ulnaria* cf. *delicatissima* (W.Smith) Aboal & P.C.Silva**	**UDEL**
SYN *Fragilaria* cf. *delicatissima* (W.Smith) Lange-Bertalot	**FDEL**
Ulnaria grunowii (Lange-Bertalot & S.Ulrich) Cantonati & Lange-Bertalot	UGRU
SYN Fragilaria grunowii Lange-Bertalot & S.Ulrich	FGNO
***Ulnaria monodii* (Guermeur) Cantonati & Lange-Bertalot (complex)**	**UMON**
***Ulnaria ulna* (Nitzsch) Compère**	**UULN**

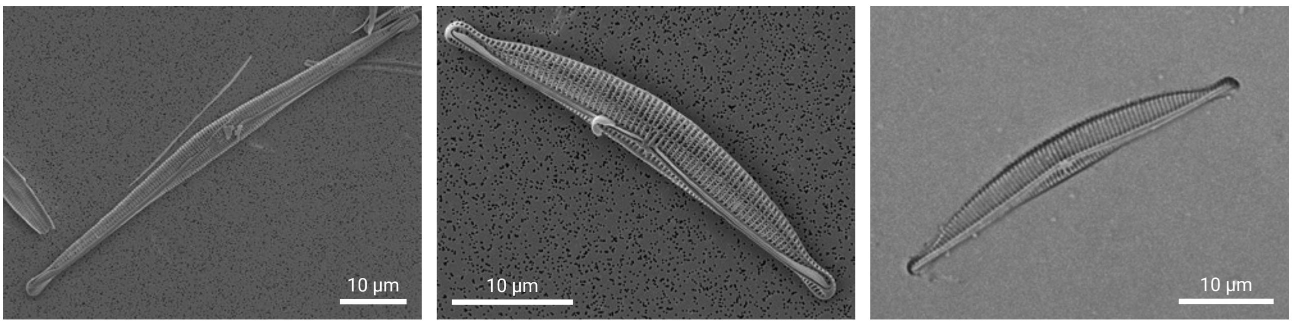

Figure 2. Morphological variations found within *Amphora* sp0 under SEM and LM found within the Eastern Karoo.

Table 2. Diatom species that were originally incorrectly identified in the Karoo with the new species allocation information

Original species name	Current species name	Reason for change
Amphora pediculus (Kützing) Grunow	*Amphora* spp.	Seven different small *Amphora* taxa were found and separated from *A. pediculus*.
Halamphora coffeiformis (C.Agardh) Mereschkowsky	*Amphora* sp.	This species was incorrectly identified in Holmes (2022) as *H. coffeaeformis* (corrected form: *H. coffeiformis*). Further investigation together with SEM has shown this is not that species and was separated from the correct identifications. It was widespread and dominant in several samples.
Brachysira neoexilis Lange-Bertalot	*Brachysira* sp. (*B. neoexilis*) shape	This species was incorrectly identified, and various morphologies were grouped together under this complex. Subsequent SEM studies have shown that these cells are not *B. neoexilis*. To differentiate this shape from the other morphologies found, the original name has been kept in the new identification to show cells were according to the distinctive *B. neoexilis* shape.
Brachysira neoexilis Lange-Bertalot	*Brachysira* spp.	Seven different morphotypes, besides the *B. neoexilis* shape, were found and allocated to different groups. Until additional data is available these are listed as separate morphotypes.
Chaetoceros sp.	*Chaetoceros* sp.	These cells had varying numbers of setae. As these may be the same species with varying stages in their life cycle or different morphologies depending on their point of attachment in chain-like colonies, along with the difficulty in identification under LM, all *Chaetoceros* species were grouped together. This genus is poorly studied in freshwaters in South Africa and no previously identified taxa could be found that share the distinct morphology areolae in the setae of the Karoo taxa.
Craticula buderi (Hustedt) Lange-Bertalot	*Craticula* cf. *buderi* (Hustedt) Lange-Bertalot	There were different morphotypes of what were thought to be *C. buderi* (Holmes 2022; Holmes et al. 2023). SEM revealed that these taxa all have distinct morphological characteristics. The species were separated based on morphological differences under LM. The ones that, under LM, fit within the 'normal' morphology was kept in this group as *C.* cf. *buderi*.
Craticula buderi (Hustedt) Lange-Bertalot	*Craticula* spp.	The species that did not fit within the *C. buderi* morphology (under LM) were placed in to eight different groups.
Diploneis elliptica (Kützing) Cleve	*Diploneis* sp. previously identified as *D. elliptica* (Kützing) Cleve	This species was originally identified using Taylor et al. (2007c, Plate 40). That identification differs from Cantonati et al. 2017 (Plate 6, Figure 1–5) and www.diatoms.org. The SEM images from the Karoo samples do not match those from Sala et al. (2018) for *D. elliptica*. It was, therefore, decided to change this species determination. This taxon was dominant in several samples in the Karoo.
Ulnaria biceps (Kützing) Compère	*Ulnaria monodii* (Guermeur) Cantonati & Lange-Bertalot comb. nov. (COMPLEX)	According to Cantonati et al. (2018), *U. biceps* is routinely misidentified. Upon rechecking the Karoo samples, it was found that not all the species fitted within the *Fragilaria biceps* (Kützing) Lange-Bertalot, *Ulnaria acuscypriacus* Lange-Bertalot & Cantonati or *U. monodii* species identifications. These species were all placed in the *U. monodii* complex. This genus needs complete revision in South Africa to gain clarity on identifications.

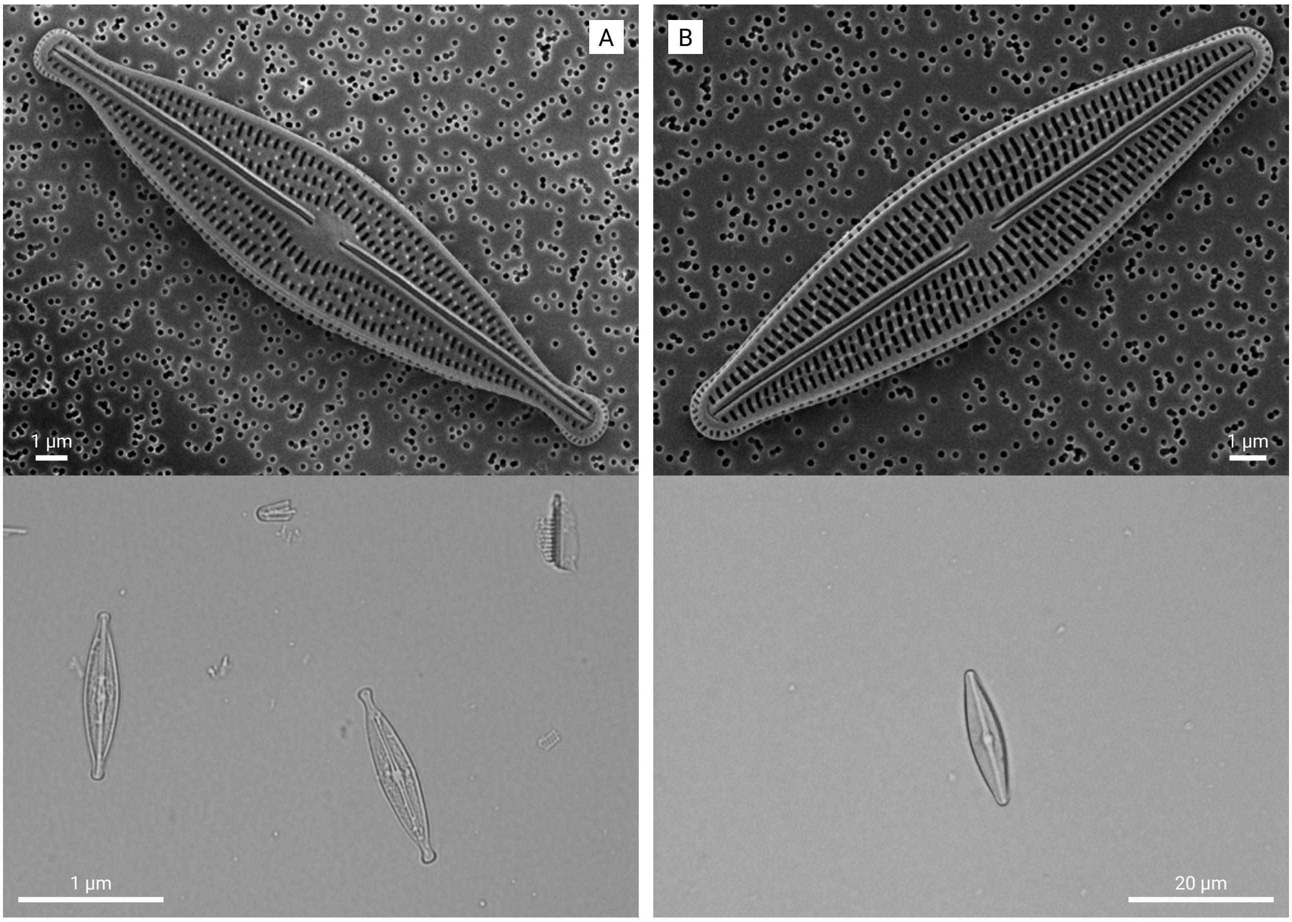

Figure 3. Two species groupings within the *Brachysira* genus found in the Eastern Karoo; A – *Brachysira* cf. *neoexilis*; B – *Brachysira* sp. 2.

There were six species groupings within the genus *Brachysira*. Although the cell in Figure 3A is similar in shape to *B. neoexilis*, under SEM it is shown not to be that species. *Brachysira* sp. 2 (Figure 3B) occurred in many samples and both sometimes in large numbers but did not occur together in the same sample.

The dominant species (from flowing water) from Holmes and Taylor (2015, n = 101) was *Nitzschia frustulum* (15.8 %) followed by *Rhopalodia gibba* [= *Epithemia gibba*] (9.6 %). The most prolific species for the Karoo Shale Gas Project, (both standing and running waters, n = 506), were *Achnanthidium minutissimum* (17.4 %), *Denticula kuetzingii* (10.1 %) and *Encyonopsis krammeri* (5.8 %).

Discussion

This species list shows the diversity in the diatom flora of the Karoo. It can be used to assist with and update freshwater diatom identification in South Africa. The list provides a basis from which to improve species occurrence information and identification.

The waters of the Karoo are alkaline (pH >6.1) with large differences in electrical conductivity (158–8400 µS/ cm), as well as wide ranges of calcium, chloride, oxidised nitrogen and sulphate (Janse van Vuuren & Taylor 2015; Holmes et al. 2023, and in progress).

The list covers species that were recorded in standing water (water reservoirs containing borehole water) and fountains (slow running water). This list excludes the information from Archibald (1983 for upper Sundays and Great Fish rivers) and upper Sundays River (Bate et al. 2004; Janse van Vuuren & Taylor 2015; Roussouw et al. 2018). No other studies on diatoms within the Karoo could be found.

As the species list is based on diatom counts from various projects that had a set number of cells counted, it must be noted that there may be species present in the Karoo that were not enumerated within that limit and are not accounted for on this preliminary species list.

Species within the *Nitzschia frustulum* group are often identified as *N. frustulum* when they are actually *N. inconspicua* or *N. soratensis*. While *N. frustulum* is known to withstand changes in osmotic pressure (and thereby fluctuating water levels, Taylor et al. 2007c), *N. inconspicua* indicates brackish-marine conditions with *N. soratensis* found in freshwater only (Trobajo et al. 2013).

Another common species complex prone to have species lumped together is *Achnanthidium minutissimum* complex. As was found during the Karoo Shale Gas Project, there were at least 24 *Achnanthidium* taxa that could not be placed in a species with certainty. The *A. minutissimum* grouping is constantly evolving as information on new species is published. Misunderstanding surrounds the identification of *Ulnaria biceps* and *Ulnaria monodii* (and similar species, Cantonati et al. 2018) in South Africa (Table 2). These species have different ecological requirements, which could lead to incorrect ecological inference. It is therefore imperative that the identification of these species be revisited.

Limitations

Although the diatom Red Lists are based on species found in Germany, it is widely known that these sensitive species occur in unimpacted habitats and may disappear in disturbed habitats. It is suggested that nitrates (and therefore human activities) could pose a threat to these species (Cantonati et al. 2022). Autecological information for diatoms in South Africa is often taken from the literature based on surveys from different regions around the world. As was shown by Holmes (2022), this information cannot be broadly superimposed on to South African conditions. Local conditions do have an effect on diatom community composition. The lack of an accessible database for the identification of South African diatoms, together with the lack of standardised data for South African ecological conditions, hampers the inclusion of these organisms as a biomonitoring tool.

This review of the Karoo diatom samples (2010 to 2012 and 2015 to 2017) with the preliminary species list presented here highlights the shortcomings for diatom identification in South Africa. A revised diatom identification guide for South African diatoms is overdue with current literature being outdated both in terms of nomenclature and taxonomy.

Several species in the Karoo are possibly, as yet, undescribed. Of the issues that came to light during the compilation of this list was the difficulty of access to historical records. The question surrounding identification of certain species, some of which are mentioned in Table 2, is an area which requires further investigation. This work may be considered as only a preliminary list of diatom species found in two projects within the Eastern Karoo.

Recommendations

For ecological studies to be effective, validated and updated checklists are essential. Checklists of an area allow for changes in community structure to be detected. As with any checklist, there is a constant need for it to be updated to remain useful. Human activities have the potential to pose great risk to biodiversity and as diatoms are good indicators of environmental change, it is important to know about any changes in species composition.

In view of the climate change crisis issues around the world, diatom records are important to infer changes in environmental conditions (past and present day). Many of the historical records in South Africa are not easily accessible to researchers. It would be highly beneficial for the scientific community if these records could be catalogued (in a central database) together with geolocation and, where possible, water chemistry before they are lost.

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Authors' contributions

M. Holmes (Nelson Mandela University and AEON-ESSRI) was responsible for both the MSc and PhD project designs used for the compilation of this species list in addition to conducting all field work (including field work costs), all diatom identification (with the assistance of J.C Taylor) and enumeration. She performed all the statistical analysis for the projects with input from both E.E. Campbell and J.C. Taylor. E.E. Campbell (Nelson Mandela University) was the supervisor of the PhD for M. Holmes for the Karoo Shale Gas Project, which included a preliminary diatom baseline of Karoo waters (2015–2017). J.C. Taylor (North-West University) was the supervisor for the MSc project for M. Holmes (2010–2012) based on the diatoms of the upper Great Fish River. He was instrumental in assisting with the set-up of the laboratory on Clifton and was co-supervisor on the above-mentioned PhD. He continues to collaborate on diatom identification. M. de Wit, as head of AEON-ESSRI (Nelson Mandela University), was responsible for all researchers under the Karoo Shale Gas Project. He unfortunately passed away during the PhD project and his contribution was therefore limited. He was, however, instrumental in the concept of the PhD project being accepted and implemented.

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