Revision of the genus *Navicula* s.s. (Bacillariophyceae) in inland waters of the Sub-Antarctic and Antarctic with the description of five new species

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A revision of the diatom genus *Navicula* s.s. in inland water samples from the Sub-Antarctic and Antarctic resulted in the description of five new species, viz. *Navicula australoshetlandica* Van de Vijver sp. nov., *N. dobrinatemniskovae* Zidarova & Van de Vijver sp. nov., *N. cremeri* Van de Vijver & Zidarova sp. nov., *N. conveyi* Van de Vijver sp. nov. and *Navicula bicephaloides* Van de Vijver & Zidarova sp. nov. The new species are extensively compared with other similar species. The morphology and taxonomy of three other *Navicula* taxa present in the same materials are briefly discussed. A critical revision of literature reports of *Navicula* taxa in the Antarctic and Sub-Antarctic region indicates that despite the large number of records the genus is rather species-poor in the Sub-Antarctic and Antarctic. From a biogeographical point of view, there is a clear separation between the Sub-Antarctic localities in the southern Indian Ocean and the islands in the southern Atlantic Ocean, with several species showing a restricted biogeography.

**Key Words:** Sub-Antarctic and Antarctic Region, Bacillariophyta, Diatoms, Morphology, *Navicula*, Taxonomy

**INTRODUCTION**

Diatoms are one of the most abundant and productive algal groups in Antarctic and Sub-Antarctic inland waters and terrestrial environments (Jones 1996; Van de Vijver & Beyens 1999). During the past decade, significant progress has been made with respect to our knowledge of the diversity and taxonomy of the nonmarine diatom flora of these regions, with a strong focus on terrestrial diatoms. These studies have resulted in the description of a considerable number of new species, mainly in the genera *Pinnularia* (Van de Vijver et al. 2002a; Van de Vijver 2008), *Diadeemis* (Le Cohu & Van de Vijver 2002; Van de Vijver et al. 2002b), *Luticola* (Van de Vijver & Matélona 2008; Esposito et al. 2008), *Muelleria* (Van de Vijver et al. 2010) and *Hantzschia* (Zidarova et al., in press). The taxonomy of diatoms from inland Antarctic and Sub-Antarctic waters has lagged behind those on terrestrial diatoms. Most studies report that the diatom floras of these systems are composed of only a limited number of taxa, mainly belonging to the genera *Achnanthes* s.l., *Pinnularia*, *Nitzschia* and *Navicula* s.l. (Jones 1996; Van de Vijver & Beyens 1999; Sabbe et al. 2003). These studies have also shown that older literature data do not always reflect true diatom diversity: distinct forms were sometimes lumped together as one single morphologically variable species (see also Mann 1999), and many taxa were force-fitted into European or North American species (Tyler 1996; Sabbe et al. 2003; Van de Vijver et al. 2005; Van de Vijver & Matélona 2008). Inevitably, these problems have also led to incorrect interpretations of the biogeography and ecology of diatoms in Antarctic regions (Sabbe et al. 2003; Van de Vijver et al. 2005).

The genus *Navicula* was originally described in 1822 by Bory de St. Vincent to accommodate isopolar biraphid species with a spindle-shaped (‘navette’), hence naviculoid, cf. Cox 1999) valve outline, uniseriate striae composed of slit-like areolae, a rather simple raphe system with an internal accessory rib, and two plate-like, girdle-appressed plastids (Round et al. 1990; Cox 1999; Lange-Bertalot 2001). The initially rather broad genus concept, including more than a thousand species and infraspecific taxa that were organised in 15 sections (Hustedt 1961–1966; Van-Landingham 1975), was modified several times (Patrick 1959; Cox 1979, 1999; Round et al. 1990; Lange-Bertalot 2001). At present, only members of the section *Lineolatae*, which includes the neotypus generis *Navicula* tripunctata (O.F. Müller) Bory, are recognized as ‘true’ *Navicula* (*Navicula* s.s.).

In temperate and tropical regions, *Navicula* s.s. species form a dominant and often highly diverse component of aquatic benthic diatom communities (Rumrich et al. 2000; Lange-Bertalot 2001; Werum & Lange-Bertalot 2004; Metzeltin & Lange-Bertalot 2009). New species are regularly being described (Levkov et al. 2007; Van de...
et al. (Kunth) Bartl. and *Navicula veneta* (in Desv.). Eleven different countries (cf. above), species diversity in the genus *Navicula* (s.s.), the list also includes taxa such as *Navicula cryptcephala* Kütz., *Navicula veneta* Kütz., or *Navicula cincta* (Ehrenberg) Ralfs, which are commonly reported from localities worldwide but have also been shown to harbour significant semicryptic and/or cryptic diversity (Pouličková et al. 2010). It is therefore not unlikely that by analogy with other genera such as *Luticola*, *Diadesmis* and *Muelleria* (cf. above), species diversity in the genus *Navicula* s.s. in the (Sub-)Antarctic may also have been underestimated due to lumping and/or force-fitting. Recent studies however have not revealed many new *Navicula* s.s. species from the (Sub-)Antarctic (e.g. only two species were described from the southern Indian Ocean islands: Van de Vijver et al. 2002a). A thorough re-investigation of *Navicula* diversity in this region is therefore timely.

In this study, we present the first revised species list of nonmarine *Navicula* s.s. species present in Sub-Antarctic and Antarctic inland waters, compiled on the basis of a critical revision of literature reports and, where necessary, (re)analyses of slides and samples from our own (Sub-)Antarctic collections (see Table 1). Four new *Navicula* taxa are described from aquatic and terrestrial materials from islands in the Atlantic sector of the southern Ocean (South Georgia, South Shetland Islands and James Ross Island); a fifth species is described from the Crozet archipelago (southern Indian Ocean). In addition, morphological descriptions are provided for three other *Navicula* taxa present in the Atlantic sector and the Antarctic Peninsula, with notes on their morphology, ecology and biogeography.

**MATERIAL AND METHODS**

**Study area**

Samples used in this study were taken from different aquatic and terrestrial habitats in South Georgia, Signy Island (South Orkney Islands), the South Shetland Islands, James Ross Island and Beak Island (Fig. 1). These islands are located in the so-called Scotia Arc and cover a latitudinal range ranging from Sub-Antarctica to Continental Antarctica (Stonehouse 1982).

South Georgia Island (54° 15′ S, 36° 45′ W), situated in the southern Atlantic Ocean at about 1400 km from the Falkland Islands, has an area of 3528 km² and is one of the largest islands in the (Sub-)Antarctic Region. It is mountainous, with 11 peaks rising to over 2000 m. The island has a cold maritime climate with a mean annual temperature of 2°C and a mean annual precipitation exceeding 1500 mm. Permanent ice and glaciers cover 58% of the total surface. Ice-free parts are covered with tundra-like vegetation.

Signy Island (60° 43′ S, 45° 38′ W) is a small island (~40 km²) belonging to the South Orkney Islands, located northeast from the tip of the Antarctic Peninsula. As defined by Stonehouse (1982), the South Orkney Islands fall into the Maritime Antarctic Province and the climatic conditions and vegetation of the islands are comparable to those of the South Shetland Islands.

The South Shetland Islands (63° 00′ S, 60° 00′ W) are a series of mountainous islands situated just north of the Antarctic Peninsula. The archipelago consists of 11 larger and many smaller islands and islets, with King George Island (1150 km²) and Livingston Island (972 km²) being the largest of them all. The islands have a typical maritime oceanic climate with mean annual temperatures around −5°C, high precipitation rates and strong westerly winds. Most of the islands are covered by permanent ice and snow cover, leaving only small parts ice-free. The vegetation on the islands is limited to lichens and mosses with only two flowering plants [*Colobanthus quitensis* (Kunth) Bartl. and *Deschampsia antarctica* Desv.]. Eleven different countries have permanent or semipermanent research stations on the islands.

The fourth locality, Beak Island (63° 36′ S, 57° 20′ S), is a small, ice-free island located in the northern Prince Gustav Channel, between Eagle Island and Tabarin Peninsula. The island is assumed to either have the same continental climate regime as James Ross Island (see following description) or a climate in between maritime and continental, as winter temperatures only occasionally fall below −20°C. Beak Island is composed of Miocene volcanic rocks and contains a few lakes and shallow ponds with small, barren catchments, partly vegetated by moss banks (see Sterken et al. in revision). Details on the lakes and their limnology can be found in Sterken et al. (in revision).

Finally, James Ross Island (64° 10′ S, 57° 45′ W), is located more to the south, in the northwestern part of the Weddell Sea, close to the northern tip of the Antarctic Peninsula. The fairly large island (2450 km²) is situated in a transitory zone between the Maritime Antarctica and Continental Antarctica regions (Øvstedal & Lewis-Smith 2001). More than 75% of the island is covered with a permanent ice sheet, leaving only the northern part ice-free where the Johann Gregor Mendel Czech Antarctic Station has been located since 2007. The temperature is comparable to the South Shetland Islands but precipitation is limited [150 mm/ y in the northern part (Aristarain et al. 1987)] with high evaporation rates reducing the formation of large open waterbodies. The terrestrial vegetation is limited to nonvascular plants (bryophyte and lichen tundra).

**Sampling and microscopy**

During various sampling campaigns in the austral summers of 1992, 1998, 2008 and 2009 on South Georgia, King George Island, Livingston Island (both South Shetland Islands) and James Ross Island, diatom samples were taken from lake sediments, soils and mosses. Despite repeated attempts, we did not succeed in establishing live cultures of the species described below, and were therefore unable to obtain sequences for molecular–phylogenetic analyses. Diatom samples for light microscopy (LM) observation were prepared following the method described in Van der
Werff (1955). Small parts of the samples were cleaned by adding 37% H$_2$O$_2$ and heating to 80°C for about 1 h. The reaction was completed by addition of KMnO$_4$. Following digestion and centrifugation (three times 10 min at 3700 g), cleaned material was diluted with distilled water to avoid excessive concentrations of diatom valves on the slides. Samples obtained from Hurd Peninsula (Livingston Island) were prepared according to the method described in Hasle & Fryxell (1970). Small subsamples were cleaned using concentrated H$_2$SO$_4$ followed by the addition of KMnO$_4$. The samples were then bleached with H$_2$C$_2$O$_4$ and washed several times with distilled water. Cleaned diatom material was mounted in Naphrax®. The slides were analysed using an Olympus BX51 microscope, equipped with Differential Interference Contrast (Nomarski) and the Colorview I Soft Imaging System. Samples and slides are stored at the National Botanic Garden (Belgium). For scanning electron microscopy (SEM), parts of the oxidized suspensions were filtered through polycarbonate membrane filters with a pore diameter of 1 micron, pieces of which were fixed on aluminium stubs after air-drying. The stubs were sputter-coated with 50 nm of Au and studied in a JEOL-5800LV at 25 kV. Morphological terminology follows Hendey (1964), Round et al. (1990) and Lange-Bertalot (2001). The morphology of the new species was compared with the ultrastructure of known European or South-American

<table>
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<tr>
<th>Sample ID</th>
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<th>Source</th>
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<td>C-BA39</td>
<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<td>C-BA87</td>
<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<td>Van de Vijver et al. 2002a</td>
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<td>C-BM224</td>
<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
</tr>
<tr>
<td>C-BM270</td>
<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<tr>
<td>C-BM271</td>
<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<td>C-BM275</td>
<td>Crozet</td>
<td>Van de Vijver et al. 2002a</td>
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<td>Van de Vijver &amp; Beyens 1997b</td>
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<td>Van de Vijver &amp; Beyens 1996</td>
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<td>SG-W368</td>
<td>South Georgia</td>
<td>Van de Vijver &amp; Beyens 1996</td>
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<td>SG-W374</td>
<td>South Georgia</td>
<td>Van de Vijver &amp; Beyens 1996</td>
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<td>SG-W384</td>
<td>South Georgia</td>
<td>Van de Vijver &amp; Beyens 1996</td>
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<td>SG-W389</td>
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<td>Van de Vijver &amp; Beyens 1996</td>
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<td>Van de Vijver &amp; Beyens 1997a</td>
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<td>JR12008-03</td>
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<td>JR12008-04</td>
<td>James Ross Island</td>
<td>this study</td>
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</table>

The type material of Navicula libonensis Schoeman (entry number NIWR 85/1683, sample 111, Lesotho, 3 December 1967, F.R. Schoeman) has been examined to compare the species with two unknown Navicula taxa. Likewise, the type material of Navicula bicephala Hust. (slide AT312, present in the Hustedt Collection in Bremerhaven) from the Kerguelen Islands has been examined to compare with a presumed N. bicephala populations from various South Atlantic islands.

A critically revised list of all Navicula s.s. taxa present in the Antarctic and Sub-Antarctic regions has been compiled on the basis of publications mentioned in Kellogg & Kellogg (2002). First, their list of Navicula taxa has been screened to remove (1) all taxa that do not belong to Navicula s.s., (2) marine taxa or (3) taxa that were reported from localities outside the Sub-Antarctic and Antarctic. Secondly, we checked the original Navicula reports listed by Kellogg & Kellogg (2002) and only retained those records that could unambiguously be confirmed on the basis of illustrations. Finally, new samples and samples from previous studies by the authors were reanalyzed for the presence of Navicula taxa. All samples and slides used in the present study are listed in Table 1.

**RESULTS**

An initial screening of the checklist published by Kellogg & Kellogg (2002) revealed that 134 taxa have been (or should still be) reassigned to other genera, i.e. they do not belong to Navicula s.s. Eleven marine taxa and 22 taxa reported from localities outside the Sub-Antarctic and Antarctic such as New Zealand, the Falkland Islands and southern Chile have also been omitted from our revised list. Some recently described taxa appeared to be later synonyms of older taxa, which further reduced the taxon count. For example, examination of the type material of the Antarctic endemic Navicula shackletonii, described by West & West (1911) from the Antarctic Continent, revealed that Navicula skuae Alfinito & Cavacini (2000) is a later synonym of this species (Van de Vijver et al., unpublished results). Likewise, Navicula adminii described by Roberts & McMinn (1999) from the Vestfold Hills (East Antarctica) is most probably synonymous with N. lineola var. perlepida, described by Grunow from Franz-Josef-land (Van de Vijver et al., unpublished results). Sixteen records could not yet be verified; these usually concerned species that were newly described at the time and which have never been reported afterwards, and whose type materials should be studied to ascertain their identity. As the descriptions and/or illustrations provided for most of the remaining 56 taxa did not allow unambiguous identification, they were not incorporated in the final revised checklist (Table 2). Because we never encountered any of these taxa in the hundreds of samples (including those listed in Table 1) we examined from the Sub-Antarctic and Antarctic, we believe that the original materials from which they were reported should be examined to verify their identity and confirm their presence in the region. As a result of our revision, at present only 14 Navicula species (including the species described in the following text) can be confirmed from the Antarctic and Sub-Antarctic Regions (Table 2).

A total of seven Navicula taxa have been found in the samples collected from the Atlantic sector of the Southern Ocean and the Antarctic peninsula [South Georgia, Signy Island (South Orkney Islands), the South Shetland Islands, James Ross Island and Beak Island] (see Table 1). Four species from the southern Atlantic Ocean islands are new to science. These are described below and compared with similar taxa from the northern hemisphere and from South America. Original descriptions are provided for the three other species, and they are briefly discussed. A fifth taxon from Ile de la Possession (Crozet archipelago, southern Indian Ocean), which was previously identified as Navicula veneta Kütz. (Van de Vijver et al. 2002a), is also described as a new species.
Table 2. List of *Navicula* species present in the Antarctic and Sub-Antarctic regions.

<table>
<thead>
<tr>
<th>Species</th>
<th>Southern Indian Ocean</th>
<th>Southern Atlantic Ocean and Antarctic Peninsula area</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Crozet Archipelago</td>
<td>Prince Edward Islands</td>
</tr>
<tr>
<td>N. gregaria Donkin</td>
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<td>X</td>
</tr>
<tr>
<td>N. bicephala Hust.</td>
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<tr>
<td>N. venetiformis Van de Vijver &amp; Beyens</td>
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<tr>
<td>N. ectoris Van de Vijver</td>
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<td>X</td>
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<td>N. conveyi Van de Vijver</td>
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<td>X</td>
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<td><em>Navicula longicrassa</em></td>
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<tr>
<td>N. rhynchocephala Kütz.</td>
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<td>N. cremert Van de Vijver &amp; Zidarova</td>
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<td>N. australoherlandica Van de Vijver</td>
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<td>N. bicephaloides Van de Vijver &amp; Zidarova</td>
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<td>X</td>
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<td>N. dobrinatemniskovae Zidarova &amp; Van de Vijver</td>
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<td>X</td>
</tr>
<tr>
<td>N. seibigiana Lange-Bertalot</td>
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<td>X</td>
</tr>
<tr>
<td>N. shackletonii West &amp; West</td>
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<td>X</td>
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<tr>
<td>N. lineola var. perlepa Grunow</td>
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</tbody>
</table>

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Figs 2–15. *Navicula australohetlandica* sp. nov. Frustules from the type population. Figs 2–13: LM, Figs 14, 15: SEM. All from BR4172.

Scale bar = 10 μm except for Figs 14, 15 for which scale bar = 1 μm.

Figs 2–13. Twelve valves showing the valve variability of the type population.

Fig. 14. External view of an entire valve. The relatively large virgae are well visible.

Fig. 15. Internal view of an entire valve.

Figs 15–24. Twelve valves showing the valve variability of the type population.
Navicula australoshetlandica Van de Vijver sp. nov.

(FIGS 2–15)


HOLOTYPE: BR–4172 (National Botanic Garden, Meise, Belgium).

ISOTYPE: PLP–158 (UA, University of Antwerp, Belgium), BRM–ZU7/56 (Hustedt Collection, Bremerhaven, Germany).

TYPE LOCALITY: King George Island, South Shetland Islands, Sample W625, Bellingshausen, (coll. L. Beyens, 19 January 1998).

ETYMOLOGY: The specific epithet refers to the archipelago where the species was found (South Shetland Islands).

MORPHOLOGY: Valves linear for most of its length with bluntly rounded, slightly cuneate apices (FIGS 2–13). Valves more elliptical at the lower end of its size range. Valve length 15–23.5 μm, width 3.9–5.0 μm (n = 54). Axial area narrow, linear. Central area elliptical to rectangular, usually asymmetric, bordered by two shorted striae. Raphe filiform with straight, drop-like central endings (FIG. 14). Terminal fissures hooked in the same direction (Fig. 14). Transapical striae radiate and slightly curved near the centre becoming parallel and finally convergent near the apices, 12–15 in 10 μm. Striae consisting of 3–5(6?) apically elongated lineolae, indistinct in LM c. 35 in 10 μm (FIG. 14). Lineolae clearly longer than the virgae, becoming as long as the virgae near the margins. Internally, lineola apertures occluded by hymenes (FIG. 15). Raphe sternum clearly asymmetrically thickened with a pronounced accessory rib, a small central nodule and small helictoglossae near the apices (FIG. 15).

ECOLOGY AND (SUB-)ANTARCTIC DISTRIBUTION: The species was found on the northeastern Antarctic Peninsula (Beak Island), the South Shetland Islands (King George Island, Livingston Island) and South Georgia. On Livingston Island this taxon was previously reported as Navicula sp. 1 by Jones et al. (1993) and as Navicula cf. vekhovii Lange-Bertalot & Genkal by Zidarova (2008).

The type population of Navicula australoshetlandica is found near the Bellingshausen Station on King George Island (South Shetland Islands). The species was present in a small, shallow mud pool surrounded by mosses, with a pH of 8.8 and a specific conductivity of 250 μS/cm. The associated diatom community was composed of Nitzschia homburgiensis Lange-Bertalot, N. cf. perminuta (Grunow) Peragallo, N. debilis Arnott, various Luticola taxa (such as, L. hiigleri Van de Vijver, Van Dam & Beyens and L. katkae Van de Vijver & Zidarova), Amphora cf. veneta Kütz. and various Pinnularia taxa. On Livingston Island, Navicula australoshetlandica is most abundant (4.8%) in a sample from lake LN-38, which is a low-elevation coastal lake (Sterken et al., unpublished results). On Hurd Peninsula (Livingston Island), the species is found in small melt-water streams, brooks and puddles surrounded by mosses as well as in wet soil and on mosses around small melt-water basins (Zidarova 2008). On Beak Island, N. australoshetlandica only occurs in a sediment core from a shallow (depth 1 m) lake with moderate specific conductance value (247 μS/cm).

REMARKS: Navicula australoshetlandica shows some similarities to N. lauca Rumrich & Lange-Bertalot, N. doehleri Lange-Bertalot, N. veneta, N. wiesneri Lange-Bertalot and N. vekhovii. Apart from the often-reported N. veneta and a single record of N. wiesneri (Kawecka et al. 1998), none of these species has been recorded from the Antarctic Region to date. Navicula lauca, described from the Altiplano in Chile (Rumrich et al. 2000), is similar in outline but has more produced valve apices and a lower stria density (10–12 vs 12–15 in 10 μm in N. australoshetlandica). Navicula doehleri, only found in Svalbard (Lange-Bertalot 2001) has a lower stria density (8–9 vs 12–15 in 10 μm in N. australoshetlandica). The ultrastructure of N. doehleri has not, however, been examined but in LM the differences between both species are quite distinct. Navicula veneta can be easily separated based on its valve outline, which is more elliptic-lanceolate with clearly convex margins and rostrate, protrated ends, and the larger width (5–6 μm vs 3.9–5.0 μm in N. australoshetlandica) (Cox 1995; Van de Vijver & Lange-Bertalot 2009). Navicula wiesneri has a lower stria density, more convex margins and a clearly asymmetrical central area (Lange-Bertalot 1993). Finally, N. vekhovii has a lanceolate valve outline with clearly convex margins (contrary to the narrowly elliptical to linear outline in N. australoshetlandica), cuneate obtuse apices and a clearly wedge-shaped (but never almost rectangular as in N. australoshetlandica) central area (Lange-Bertalot & Genkal 1999). In SEM, the central raphe pores are larger in N. vekhovii (Lange-Bertalot & Genkal 1999, plate 14, fig. 7). Similarity can also be found with the smaller Navicula taxa from the complex around N. tenelloides Hust. such as N. arctotenelloides Lange-Bertalot & Metzeltin and N. pseudotenelloides Krasske. Navicula arctotenelloides has a typically lanceolate valve outline with more convex margins and a fairly constant number of 14.5–15 striae in 10 μm (Lange-Bertalot 2001) vs 12–15 in N. australoshetlandica. Navicula pseudotenelloides has narrower linear-lanceolate to elliptic-lanceolate valves, with less convex margins, and a...
Figs 30–45. *Navicula cremeri* sp. nov. Frustules from the type population. Figs 30–42: LM. Figs 43–45: SEM. All from BR4194. Scale bar = 10 μm except for Fig. 59 for which scale bar = 1 μm.

**Figs 30–42.** Thirteen valves showing the valve variability of the type population.

**Fig. 43.** External view of an entire valve.

**Fig. 44.** External detail view of the central area with the expanded central raphe endings.

**Fig. 45.** Internal view of an entire valve.

**Fig. 46.** *Navicula libonensis*. Valve from the type material.

**Figs 47–60.** *Navicula conveyi* sp. nov. Frustules from the type population. Figs 46–57: LM, Figs 58–60: SEM. All from BR4196. Scale bar = 10 μm except for Fig. 59 for which scale bar = 1 μm.
smaller central area (Lange-Bertalot 2001, p. 301, figs 21–27).

The most similar taxon to *Navicula australoshetlandica* is however *N. dobrinatemniskovae* Zidarova & Van de Vijver, described in the following section. The latter can be easily distinguished on the basis of valve shape and dimensions, and its overall more robust appearance.

**Navicula dobrinatemniskovae** Zidarova & Van de Vijver *sp. nov.*

(Figs 16–29)

**DESCRIPTION:** Valvae angustes ellipticae ad angustae lanceolatae apicibusque cuneatis, subrostratis. Longitudo (15.7) 22.4–26.5 µm, latitudo 4.1–4.6 (4.8) µm. Area axialis angusta, leviter dilatans ad aream centralem. Area centrals moderate lata, paene rectangularis, marginata duabus stris curitis. Raphe filiformis, paene recta ad leviter undulata in media parte valvae. Porri centrales distantes, moderate expansi, guttiformes. Fissurae terminations formatae similis signo interrogaatis. Striae transapicales moderate radiatae prope aream centrals ad convergentes ad polys, 14–15 in 10 µm. Lineolae vix discernibles in microscopico photonicum, circa 35–40 in 10 µm.

**HOLOTYPE:** BR-4195 (National Botanic Garden, Meise, Belgium).

**ISOTYPE:** PLP-159 (UA, University of Antwerp, Belgium), BRM-ZU7/57 (Hustedt Collection, Bremerhaven, Germany).

**TYPE LOCALITY:** North from the Bulgarian Antarctic Base, Hurd Peninsula, Livingston Island, the South Shetland Islands, Antarctica, sample LIV12-1/2008 (coll. R. Natcheva, 22 February 2008).

**ETYMOLOGY:** The species is dedicated to Prof. D.Sc. Dobrina Tenniskova-Topalova on the occasion of her 75th birthday.

**MORPHOLOGICAL OBSERVATIONS:** Valves narrowly elliptical to narrowly lanceolate with cuneate to subrostrate apices (Figs 16–27). Valve length (15.7) 22.4–26.5 µm, breadth 4.1–4.6 (4.8) µm (n = 23). Axial area narrow, slightly widened near the centre. Central area moderately large, transversally expanded, almost rectangular in shape, bordered by two very short striae of usually one to three lineolae. Raphe filiform, almost straight, sometimes slightly undulating near the valve centre. Central pores quite distant, moderately expanded and drop-like (Fig. 28). Terminal raphe fissures ‘?’-shaped, unilaterally deflected to the secondary side (Fig. 28). Striae radiate near the centre, becoming convergent near the apices, 14–15 in 10 µm, consisting of three to seven lineolae. Lineolae not discernible in LM, c. 35–40 in 10 µm (Fig. 29). In SEM, lineolae longer than the virgae, becoming shorter near the apices.

**ECOLOGY AND (SUB)-ANTARCTIC DISTRIBUTION:** The largest population of *N. dobrinatemniskovae* was found in a small puddle on a rock covered with the moss *Sanionia georgico-uncinata* (Müll. Hal.) Ochyra & Hedénäs. The species was usually observed on moderately to very wet mosses in and around small melt-water basins. The associated diatom flora includes *Luticola nigleri*, *Pinnularia subantarctica* var. *elongata* (Manguin) Van de Vijver & Le Cohl and various *Diadesmis*, *Muelleria* and *Hantzschia* species.

To date *Navicula dobrinatemniskovae* is only known from Livingston Island. It is possible that in the past the species has been confused with *Navicula tenelloides* or *N. veneta*.

**REMARKS:** *Navicula dobrinatemniskovae* mostly resembles the species around the *N. tenelloides*-species complex, e.g. *Navicula tenelloides*, *N. pseudotenelloides* and *Navicula arctotenelloides*. *Navicula tenelloides* has slightly narrower valves (up to 4 µm vs 4.1–4.8 µm), densely spaced strongly radiate striae (15–17 vs 14–15 in 10 µm) and a small central area (Lange-Bertalot 2001). The Arctic *Navicula pseudotenelloides* (Krasske 1938) has narrow linear-lanceolate to elliptic-lanceolate valves with obtusely rounded but not protracted ends and a small, rounded central area. *Navicula arctotenelloides*, another species from the Arctic (Lange-Bertalot et al. 1996), is shorter (14–20 µm vs usually 22.4–26.5 µm) with elliptic-lanceolate valve outline and never protracted ends. Other similar taxa are *Navicula lauca*, *N. notha* and *N. veneta*. The cosmopolitan *N. veneta* has broader valves (5–6 µm vs 4.1–4.8 µm) with shortly protracted ends (Cox 1995; Lange-Bertalot 2001). *Navicula lauca*, known from Chile (Rumrich et al. 2000), differs by having a coarser striaion (10–12 vs 14–15 striae in 10 µm) and a larger width (4.5–6 µm). *Navicula notha* is similar in valve outline but has central pores that are clearly deflected toward the primary side, a smaller central area and strongly radiate, more densely spaced striae, 15–17 in 10 µm (Lange-Bertalot 2001, p. 89, 317, figs 16–28).

*Navicula dobrinatemniskovae* can be confused with two other Antarctic *Navicula* species: *N. cremeri* and *N. australoshetlandica*. *Navicula australoshetlandica* differs mostly by the valve outline with no protracted ends, generally smaller length (up to 22.5 µm) and slightly coarser striaion (12–15 striae in 10 µm vs 14–15 in 10 µm in *N. dobrinatemniskovae*). The lineolae in *N. dobrinatemniskovae* near the valve margins are shorter than in *N. australoshetlandica*. *Navicula cremeri* has larger lanceolate valves with more convex margins (valve length 27.5–32.0 µm, valve width 5.5–6.5 µm) and an almost elliptic central area.

**Navicula cremeri** Van de Vijver & Zidarova *sp. nov.*

(Figs 30–45)

**DESCRIPTION:** Valvae lanceolatae ad paene rhombicae apicibus clare protractis, cuneatis subrostratis ad subrostratis. Longitudo 27.5–32 µm, latitudo 5.5–6.5 µm. Area axialis angusta, linearis, numquam dilatans ad aream centralem.
**Navicula cremeri**

**DESCRIPTION:** Valvae anguste ellipticae ad anguste lanceolatae. Apertoria prope aream centralem, parallelollae ad etiam convergentes ad polos. 14–15 in 10 µm. Lineolae leviter discernibiles in microscopio photonico, circa 35 in 10 µm, longiores quam virgas.

**ETYMOLOGY:** The specific epithet refers to our dear colleague Dr. Holger Cremer (TNO, Utrecht, The Netherlands).

**MORPHOLOGY:** Valves lanceolate to almost rhombic with produced, cuneate-subrostrate to subrostrate apices (Figs 30–42). Valve length 27.5–32.0 µm, valve width 5.5–6.5 µm (n = 27). Axial area narrow, not widened towards the central area. Central area small, elliptical to rectangular (Fig. 43). Raphe filiform to weakly lateral. External central raphe endings straight with drop-like central pores (Fig. 44). Terminal raphe fissures hooked towards the secondary side (Fig. 43). Transapical striae radiate near the valve centre, becoming parallel to strongly convergent towards the apices, 14–15 in 10 µm. Striae consisting of three to eight apically elongated lineolae, visible in LM, 30–35 in 10 µm (Fig. 43). Lineolae are always longer than the virgae, almost not shortened towards the valve margins. Internally, lineolae are occluded by hymenes (Fig. 45). Raphe sterna asymmetrical thickened forming a small central nodule and with small helictoglossae near the apices (Fig. 45).

**ECOLOGY AND (SUB-)ANTARCTIC DISTRIBUTION:** Navicula cremeri has so far been observed with certainty on South Georgia, James Ross Island and Livingston Island. The smallest population was found on South Georgia in a slightly alkaline (pH = 7.4) lake with very low specific conductance (39 µS/cm). On Livingston Island, the species was found in ponds, on rocks irrigated by melting snow and in soils. On James Ross Island, N. cremeri has only been observed in lakes, not in seepage areas. Based on the physico-chemical data, the species shows a preference for circumneutral to slightly alkaline waters (pH 7.2–7.6) with moderate specific conductance values (120–184 µS/cm), low total phosphate levels (9.7–14.5 µg/l) and almost no NO2-N (< 0.01 µg/l).

**REMARKS:** Navicula cremeri can be confused with *N. libonensis* Schoeman, *N. notha* Wallace, *N. leptostriata* Jørgensen, *N. streckeriae* Lange-Bertalot & Witkowski, *N. vandamii* Schoeman & Archibald and its variety *mertensiae* Lange-Bertalot and *N. veneta*. Both *N. notha* and *N. leptostriata* differ by having a smaller valve width (up to 5.5 µm vs 5.5–6.5 in *N. cremeri*), densely spaced (> 15 in 10 µm in both species) strongly radiate striae, a small central area and central raphe endings deflected to the primary side (Lange-Bertalot 2001, plate 40, fig. 9). *Navicula vandamii* and its variety *mertensiae* also have deflected central raphe endings (Lange-Bertalot 2001). Both taxa are also smaller than *N. cremeri* (4.6–5.8 µm and 4.5–5.0 µm resp. in *N. vandamii* and its var. *mertensiae* vs 5.5–6.5 µm in *N. cremeri*) with a higher striae density (up to 17 in *N. vandamii* and 18 in var. *mertensiae*) with coarser lineolae. *Navicula veneta* has less protracted rostrate valve ends and a rectangular central area (Lange-Bertalot 2001). Finally, *N. streckeriae* has a similar valve outline but is much larger (26–55 µm in length and 8–10.5 µm in width) with less strongly radiate striae (9–10 in 10 µm) that are much coarser.

**Navicula conveyi Van de Vijver sp. nov.**

(Figs 47–60)

**DESCRIPTION:** Valvae anguste ellipticae ad anguste lanceolatae apicibus protractis, cuneatis ad subrostratis ad subrostratis. Longitudo 23–29 µm, latitudo 4.8–5.8 µm. Area axialis angusta, linearis, leviter dilatans ad aream centralem. Area centralis rectangularis ad cuneata, formans subfasciam asymmetrical marginatum 2–3 striis curitis. Raphe filiformis, recta poris centralis leviter deflexis, guttiformibus. Striae transapicales moderate radiatae in media parte valvae ad parallellae et forte convergentes ad apices, 13–15 in 10 µm. Lineolae discernendae in microscopio photonico, circa 30 in 10 µm.

**HOLOTYPE:** BR-4196 (National Botanic Garden, Meise, Belgium).

**TYPE LOCALITY:** Sample BA087, Vallée des Branloires, Ile de la Possession, Crozet Archipelago (Southern Indian Ocean) (coll. B. Van de Vijver, coll. date 30 November 1999).

**ETYMOLOGY:** The species is dedicated to our colleague Dr. Pete Convey (British Antarctic Survey, Cambridge, UK).

**MORPHOLOGICAL OBSERVATIONS:** Valves narrowly elliptical to narrowly lanceolate, with produced, cuneate-subrostrate to subrostrate apices (Figs 47–57). Valve length 23–29 µm, valve width 4.8–5.8 µm (n = 15). Axial area narrow, slightly widening towards the central area. Central area elliptical to rectangular, often slightly asymmetrical, bordered by two to three shortened striae (Figs 58, 59). Raphe filiform, straight with droplike, central pores weakly deflected towards the secondary side (Fig. 59). Striae radiate near the valve centre, becoming parallel to convergent towards the apices, 13–15 in 10 µm. Lineolae clearly discernible in LM, c. 30 in 10 µm (Fig. 58), slightly longer than or as long as the virgae, only slightly shortening towards the margins. Internally, they are occluded by hymenes (Fig. 60). Raphe sterna asymmetrical thickened forming a narrow central nodule and small helictoglossae near the apices (Fig. 60).

**ECOLOGY AND (SUB-)ANTARCTIC DISTRIBUTION:** So far, *Navicula conveyi* has only been found on Ile de la Possession.
The largest population of *N. conveyi* was observed in very wet, red soil under a moss cover, close to iron-containing carbonate springs in the largest valley on Ile de la Possession. Accompanying taxa were *Achnanthidium minutissimum* (Kütz.) Czarnecki, *Achnanthidium modestiforme* (Lange-Bertalot) Van de Vijver, *Navicula gregaria* and *Pinnularia microstauron* var. *nonfasciata* Krammer. The physico-chemical characteristics of the soil point to a slightly acidic (pH 5.6) nutrient-poor [low phosphate (< 0.05 mg/l) and ammonium (0.29 mg/l) levels] environment with a low specific conductance (123 μS/cm). Other (very small) populations have been found in wet mosses in the same valley.

REMARKS: The species was originally identified as *Navicula veneta* (in Van de Vijver et al. 2002a). *Navicula veneta*, however, has similar valve dimensions but a different valve outline (being more rhombic-lanceolate) and a higher lineola density (35 vs 30 in 10 μm) making it impossible to discern the areolae in LM.

The most similar species however is *Navicula libonensis* described from Lesotho (Schoeman 1970) (Fig. 46). Both species can be separated on the basis of valve dimensions and shape of the central raphe endings. Analysis of the type material of *N. libonensis* (Fig. 46) revealed that the latter has a lower number of striae (11–12 vs 14–15 in 10 μm) and a lower number of lineolae (c. 25 vs 30–34 in 10 μm) giving the species a coarser appearance. In addition, the central raphe endings are smaller in *N. libonensis;* whereas, in *N. conveyi* they are clearly droplike (even in LM). *Navicula cremeri* has similar valve dimensions but its valves are somewhat wider (5.5–6.5 μm vs 4.8–5.8 μm). *Navicula cremeri* also differs in having a more lanceolate to even slightly rhombic valve shape.

*Navicula cf. seibigiana* Lange-Bertalot

(Figs 61–76)

**MORPHOLOGICAL OBSERVATIONS:** Valves lanceolate to rhombic-lanceolate with rounded, never produced apices (Figs 61–73). Valve length 23–30 μm, valve width 5.5–6.5 μm (n = 10). Axial area narrow, slightly widening towards the central area. Central area very small, more or less rhombic. Raphe filiform, situated on a thickened, raised sternum. Central raphe endings weakly deflected ending in drop-like central pores (Fig. 76). Terminal fissures both hooked towards the secondary side (Fig. 74). Transapical striae strongly radiate in the valve centre to parallel or convergent near the poles, 8–10 in 10 μm, more widely spaced in the centre of the valve. Striae composed of small lineolae, difficult to resolve in LM, > 35 in 10 μm (Figs 74, 76). Near the apices, one transapical slit present...
Navicula sei-bigiana was originally described from a small river in the Swiss Alps (Lange-Bertalot 1993). The largest populations on James Ross Island were found in the epipelon and epilithon of several larger lakes although in some seepages and moss vegetations the species was also present. Most lakes where N. seibigiana was found are characterized by moderate to high specific conductance values (100–200 µS/1), an almost circumneutral to slightly alkaline pH (6.8–7.6) and moderate nutrient values (total phosphate 46–592 µg/l). Accompanying taxa include several Nitzschia taxa such as N. homburgiensis, N. cf. pusilla Grunow and N. perminuta, Navicula gregaria Donkin and Luticola cohnii (Hilse) Mann. In the South Shetland Islands, the species is occasionally found in a wide variety of habitats including streams, brooks, pools, wet rocks and soils (Fermani et al. 2007; Zidarova 2008, as N. cincta).

**Navicula cf. seibigiana** is also present on James Ross Island (Van de Vijver, unpublished results) and on the Antarctic Continent (Esposito et al. 2008, as N. cincta). Kellogg & Kellogg (2002) did not mention the species in their list but it is possible that all records listed under Navicula eidrigeana Carter or N. cincta represent N. cf. seibigiana.

**REMARKS:** The type of *N. seibigiana* (shown in Lange-Bertalot 1993, plate 44, figs 6–15) shows some differences with the Antarctic populations. The valve apices in *N. seibigiana* are narrower than in the Antarctic populations, giving the European valves a more slender outlook. Second, the central area is less expanded in the European *N. seibigiana* compared to the Antarctic valves. Finally, the lineolae seem to be shorter making the virgae larger than the striae in the Antarctic populations (Lange-Bertalot 1993, p. 253, figs 14, 15). However, the valve dimensions, striation pattern and raphe structure are all similar in both populations making these differences too small to justify the separation of both populations.

Although the ultrastructure of the Antarctic *N. cf. seibigiana* presents some important similarities with *N. cincta*, such as the continuous internal central raphe endings, the presence of the raised raphe sternum and the lineolae structure (Lange-Bertalot 1993, 2001), the taxon is quite different in outline being more rhombic-lanceolate. Navicula cincta on the other hand has typically linear to linear-lanceolate valves with almost parallel margins, and only near the apices is the valve width diminishing, terminating in rather acutely rounded apices. The number of striae is markedly higher in *N. cincta* (photographs of type material but no description in Lange-Bertalot 2001) in comparison with *N. cf. seibigiana* (11–13 vs 8–10 in 10 µm, respectively). Finally, in *N. cincta*, the striae are less radiate and the central area is more asymmetric than in *N. cf. seibigiana*. Navicula wiesneri is also similar but lacks the raised raphe sternum and the alveolate internal structure of the striae, and has a higher stria density (11.5–14 in 10 µm). Navicula eidrigeana Carter is longer and wider with a comparable stria density but a lower number of lineolae (24 in 10 µm).

**Navicula rhynchocephala Kütz.**

(Figs 77–82)

**MORPHOLOGICAL OBSERVATIONS:** Valves lanceolate and rostrate-capitate to capitulate-produced apices (Figs 77–81). Valve length 42–55 µm, valve width 8.1–10.5 µm (n = 10). Axial area narrow, slightly widened near the central area. Central area elliptical, asymmetric. Raphe slightly lateral with straight central endings and drop-like central pores. Transapical striae radiate to convergent at the apices, 11–12 in 10 µm, more spaced near the central area. Lineolae distinct in LM, c. 25 in 10 µm.

The ultrastructure could not be observed due to the rarity of the species in the samples. Internally, well-developed raphe sternum present terminating in a small helictoglossa (Fig. 82).

**ECOLOGY AND (SUB-)ANTARCTIC DISTRIBUTION:** On South Georgia, *N. rhynchocephala* was found in very small populations in several lakes with a circumneutral pH (7.3–7.8) and low specific conductance values (20–60 µS/cm). In mosses and soils, the species was never observed. Accompanying taxa include Psammothidium subatamoides (Hust.) Bukhtitarova & Round, Fragilaria neoproducta Lange-Bertalot, Eolimna minima (Grunow) Lange-Bertalot and Cavrnula pseudocutiformis (Hust.) D.G. Mann & A.J. Stickle. On Horseshoe Island (Wasell & Häkansson 1992) the species was only found in a sediment core.

**Navicula rhynchocephala** has been reported from South Georgia (Wasell 1993; Van de Vijver & Beyens 1996), the South Shetland Islands (Liu & Jiang 1990; Luscinska & Kyc 1993; Häkansson & Jones 1994) and the Antarctic Peninsula (Horseshoe Island: Wasell & Häkansson 1992). In the southern Indian Ocean, *N. rhynchocephala* was found in one moss sample from a lake on Marion Island (Prince Edward Islands) with a circumneutral pH (7.1) and a low specific conductance (60 µS/cm) (Van de Vijver et al. 2004).

**REMARKS:** Specimens from the South Georgian population of *N. rhynchocephala* are morphologically identical to those from Europe. Cox (1987) discusses the morphology of some European *N. rhynchocephala* populations and based on the SEM pictures shown, it is clear that there are no morphological or dimensional differences between the Antarctic and European populations. The species is also difficult to confuse with other taxa. Navicula rhynchothella Lange-Bertalot and *N. vaneei* Lange-Bertalot differ in valve dimensions, areolar density and raphe structure (Lange-Bertalot 2001).

**Navicula bicephaloides Van de Vijver & Zidarova sp. nov.**

(Figs 83–96)

**DESCRIPTION:** Valvae anguste ellipticae ad lineares apicibus protractis, rostrate-capitatis. Longitudio 17–22 µm, latitudo 3.0–3.5 µm. Area axialis angusta, graduatim dilatata ad aream centrallem. Area centralis parvissima ad paene nulla 1–2 striis irregulariter abbreviatis magisque distantibus. Raphe filiformis terminationibus centralibus leviter deflexis ad latus...
secundus cum poris guttiformibus. Striae transapicales clare radiatae, parallelae ad convergentes ad apices, 14–16 in 10 μm. Lineolae non discernendae in microscopio photonico, circa 40 in 10 μm.

**Differt a** Navicula bicephala Hust. marginibus stricte parallellis, latitudine inferiori (3.0–3.5 μm versus 4–5 μm) et 14–16 striis in 10 μm (versus 16–18 in 10 μm).

**HOLOTYPE:** BR-4197 (National Botanic Garden, Meise, Belgium).

**ISOTYPE:** PLP-162 (UA, University of Antwerp, Belgium), BRM-ZU7/60 (Hustedt Collection, Bremerhaven, Germany).

**TYPE LOCALITY:** Byers Peninsula, Livingston Island, sample LIV 7 (coll. A. Quesada, 14 December 2006).

**ETYMOLOGY:** The specific epithet ‘bicephaloides’ refers to the morphological resemblance to Navicula bicephala Hust.

**MORPHOLOGICAL OBSERVATIONS:** Valves narrowly elliptical to linear with produced, rostrate-capitate apices (Figs 83–94). Valve length 17–22 μm, valve width 3.0–3.5 μm (n = 15). Axial area narrow, gradually widening towards the central area. Central area very small to almost nonexistent due to one to two irregularly shortened, more distantly spaced central striae (Figs 83–94). Raphe filiform. Central raphe endings weakly deflected to the secondary side terminating in small, drop-like pores (Fig. 95). Transapical striae clearly radiate, more or less abruptly changing to parallel and convergent near the apices, 14–16 in 10 μm. Lineolae not visible in LM, c. 40 in 10 μm. Central raphe endings straight. Small helictoglossae present (Fig. 96). Lineolae located in alveolus-like grooves, occluded by hymenes (Fig. 96).

**ECOLOGY AND SUB-ANTARCTIC DISTRIBUTION:** *Navicula bicephaloides* was found on the South Shetland Islands (Van de Vijver & Beyens 1997b; Zidarova 2008, as *N. bicephala*) and the South Orkney Islands (Oppenheim 1990; Oppenheim & Greenwood 1990; Jones et al. 1993; Häkansson & Jones 1994 as *N. bicephala*). The species has not been so far found on South Georgia, James Ross Island and the Antarctic continent. Zidarova (2008) recorded the species in soils and on mosses, although it is extremely rare (Zidarova, personal observation). *Navicula bicephala* has been found on all islands in the southern Indian Ocean (Hustedt 1952; Le Cohu & Maillard 1986; Van de Vijver et al. 2001, 2002a, 2004, 2008), while this species is absent on the islands in the southern Atlantic Ocean.

The new species seems to prefer mosses and wet soils but further physico-chemical data are lacking (Van de Vijver & Beyens 1997b; Zidarova 2008).

**REMARKS:** *Navicula bicephaloides* has slightly smaller (valve width 3.0–3.5 μm versus 4–5 μm in *N. bicephala*), more or less linear valves in comparison with *N. bicephala* from the southern Indian Ocean islands, giving the latter a more robust outline. In addition, the number of striae in the new species is lower than in *N. bicephala* (14–16 vs 16–18 in 10 μm), although it is generally accepted that smaller valves from the same size reduction cycle show a higher number of striae than the larger valves (Van de Vijver et al. 2006). Although the differences are quite obvious between the two taxa, it is clear that they still bear a large similarity.

In 1900, P.T. Cleve described *Pinnularia sphaerophora* from Isla Desolacion, an island in the Tierra del Fuego region. Apart from a single mention by Hustedt in 1952, the taxon has never been reported in the literature. According to Hustedt *P. sphaerophora* should be transferred to *Navicula*. He states that it is quite similar to *N. bicephala* but differs from this species in its more capitate apices and less radiate striae. Based on the line drawing in Cleve (1900), it is clear that *P. sphaerophora* has more protracted, capitate apices and only a very small central area since the striae are not or only very slightly shortened. Unfortunately, we were unable to locate the type material of *P. sphaerophora* so its conspecificity with *N. bicephala* cannot be verified.

Other taxa that resemble *N. bicephaloides* include *Navigula longicephala* Hust., *Navigula vilaplanii* (Lange-Bertalot & Sabater) Lange-Bertalot & Sabater and *Navigula notha* Wallace. *Navigula longicephala*, recently found on Ile de la Possession (Van de Vijver, unpublished research) is smaller with a higher stria (18–21 vs 14–16 in 10 μm) and lineola density (c. 50 vs 40 in 10 μm) and lacks the more distant central raphe pores. *Navigula vilaplanii* is much smaller (max. 17 μm long) with a higher stria density (19–22 vs 14–16 in 10 μm) and acute apices. The stria arrangement near the central area differs markedly in having more than one stria in *N. bicephaloides* and at least two in *N. vilaplanii* (Sabater et al. 1990, p. 189, figs 7–10). Finally, *N. notha* belongs to a different section (Alinea) with the central raphe endings turned towards the primary side, in contrast with *N. bicephaloides* which belongs to the section *Navigula* (Lange-Bertalot 2001).

**Navigula gregaria** Donkin (Figs 97–106)

**MORPHOLOGICAL OBSERVATIONS:** Valves broadly elliptical to broadly lanceolate with rostrate-capitate to capitellate-produced apices (Figs 97–104). Valve length 20–42 μm, valve width 5.5–9.4 μm (n = 25). Axial area very narrow. Central area small, typically asymmetric with one side being semi-elliptic and the other almost rectangular. Raphe filiform, situated on a thickened, raised sternum (Fig. 105). Central raphe endings deflected to the primary side, slightly expanded. Transapical striae radiate near the valve centre, becoming parallel and strongly convergent towards the apices, 15–17 in 10 μm. Lineolae distinct in LM, 25–30 in 10 μm (Fig. 105). Internally, the lineolae are occluded by hymenes (Fig. 106). The raphe is situated on a raised raphe sternum with straight central endings and small terminal helictoglossae (Fig. 106).

**ECOLOGY AND SUB-ANTARCTIC DISTRIBUTION:** *Navigula gregaria* can be found in a wide variety of aquatic habitats such as pools, lakes, rivers, streams, ponds and occasionally on wet mosses or soils (Van de Vijver et al. 2002a; Zidarova 2008).

This cosmopolitan species is widespread in the entire Antarctic and Sub-Antarctic region. Kellogg & Kellogg
**Figs 77–82.** *Navicula rhynchocephala*. Frustules from the South Georgian population. Figs 77–81: LM, Fig. 82: SEM. All from SGW384. Scale bar = 10 μm.

- **Fig. 75.** External view of an entire valve.
- **Fig. 76.** Internal view of an entire valve.
- **Figs 77–81.** Five valves showing the valve variability of the South Georgian population.

**Figs 83–96.** *Navicula bicephaloides* sp. nov. Frustules from the type population. Figs 83–94: LM. Figs 95, 96: SEM. All from BR4197. Scale bar = 10 μm.

- **Figs 83–94.** Twelve valves showing the valve variability of the type population.
(2002) list all reported observations ranging from the South Shetland Islands (e.g. Kawecka & Olech 1993), South Orkney Islands (e.g. Håkansson & Jones 1994), South Georgia (e.g. Van de Vijver & Beyens 1996), James Ross Island (Björck et al. 1996) and the Antarctic Continent (Roberts & McMinn 1996).

**REMARKS:** Based on their morphological features, all Antarctic populations unmistakably represent *Navicula gregaria* as shown in Cox (1987, 1995) who investigated the Donkin type material of *N. gregaria*. No other *Navicula* species presents a similar combination of features. *Navicula supergregaria* Lange-Bertalot & Rumrich, described from the Andes, is larger with rostrate to subrostrate apices (Rumrich et al. 2000).

**DISCUSSION**

Despite the fact that Kellogg & Kellogg (2002) listed 238 taxa belonging to *Navicula* s.l. in their checklist of nonmarine and littoral diatoms of the Sub-Antarctic and Antarctic, our revision resulted in a final list of only 14 *Navicula* (s.s.) taxa whose presence could be confirmed from inland waters and terrestrial environments in these regions (Table 2). Surprisingly, this list includes five new species, which are described in the present study. Most of these resemble species described from Europe, North America or elsewhere, and the fact that some of them have previously been reported under other names from the Sub-Antarctic or Antarctic, suggests that in these regions force-fitting is as common in *Navicula* as in other genera such as *Stauroneis* (Van de Vijver et al. 2005), *Hantzschia* (Zidarova et al. 2010), *Muelleria* (Van de Vijver et al. 2010) and *Luticola* (Van de Vijver & Mataloni 2008). Most other taxa listed in Kellogg & Kellogg (2002) were excluded from our final list because (1) they are marine; (2) they were reported from outside the Sub-Antarctic and Antarctic; (3) they do not belong to *Navicula* s.s.; (4) they are later synonyms of older names; and (5) their presence in the region and/or their identity could not be unambiguously confirmed on the basis of the descriptions and/or illustrations provided in the literature. Although the total number of nonmarine *Navicula* species in the Sub-Antarctic and Antarctic may again increase as older slides and materials are re-examined or when new materials from undesampled regions are studied, we believe this increase will be limited given the fact that none of the authors have as yet found any other *Navicula* species in the hundreds of samples from numerous Sub-Antarctic and Antarctic localities that have been examined during the past 15 years. It thus seems that overall species diversity in nonmarine *Navicula* s.s. is surprisingly low in the Sub-Antarctic and Antarctic, especially when compared with other genera such as *Pinnularia*, *Muelleria*, *Diadesmis* or *Stauroneis* (Van de Vijver et al. 2002a, 2005, 2010). While recent revisions of e.g. *Muelleria* (Spaulding et al. 1999; Van de Vijver et al. 2010) and *Stauroneis* (Van de Vijver et al. 2004, 2005) resulted in a significant increase in the total number of species known from these regions, our revision of *Navicula* actually decreased this number. In stark contrast with *Navicula*, these genera, despite overall lower global species diversity, actually display a disproportionately high diversity in the (Sub-)Antarctic region. The low diversity of *Navicula* in inland aquatic and terrestrial habitats in the Sub-Antarctic and Antarctic is probably due to the absence of suitable habitats. Most *Navicula* are typical of meso- to eutrophic lakes and larger, permanent rivers (Lange-Bertalot 2001). In our study area, moist, terrestrial habitats such as seepage areas, moss vegetation, wet soils and temporary pools and brooks form the majority of permanent or semi-permanent freshwater and terrestrial habitats (Bergstrom et al. 2006). The genera *Luticola*, *Diadesmis*, *Pinnularia* and *Muelleria* are all known to prefer such aerial conditions (Le Coo & Van de Vijver 2002; Van de Vijver & Mataloni 2008; Van de Vijver et al. 2010).

Our results underscore recent findings that show that the (Sub-)Antarctic region is characterized by a largely endemic diatom flora (Sabbe et al. 2003; Van de Vijver et al. 2005; Vyverman et al. 2007). Only 3 out of 14 *Navicula* taxa present in the region are found outside the (Sub-)Antarctic and appear to have a cosmopolitan distribution (*N. gregaria, N. longicephala, N. rhynchocephala*). However, given the widespread occurrence of (semi)cryptic diversity in diatoms (Behnke et al. 2004; Mann et al. 2004; Bezsteri et al. 2005; Mann et al. 2008), including *Navicula* (Pouličková et al. 2010; Van Elslander et al. 2009), their species structure and biogeography still remains to be critically assessed using molecular genetic techniques.

Finally, our revision of Sub-Antarctic and Antarctic *Navicula* taxa also confirms previous studies in other genera (such as *Luticola*, *Muelleria* and *Stauroneis*) which show that the aquatic and terrestrial diatom floras of the southern Indian Ocean islands are very different from the islands in the southern Atlantic Ocean. Apart from the cosmopolitan species *N. gregaria* and *N. rhynchocephala* (Lange-Bertalot 2001), no species are shared between the two island groups (Table 2). Our results show that further revisions of Antarctic nonmarine diatoms are essential for biogeographical studies in the area.

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REFERENCES


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