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Morphological study of the marine planktonic diatom *Chaetoceros castracanei* Karsten (Bacillariophyceae) from Antarctic waters, with a discussion on its possible taxonomic relationships

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Abstract

Phytoplankton samples were collected along the north coast of the Antarctic peninsula, the Weddell Sea and the Gerlache Strait, in different seasons in 1985, 1986, 1999, and 2000–2002. *Chaetoceros castracanei* Karsten, a fairly rare species was present in the samples; its morphology, taxonomy and distribution have not been recently investigated. This species occurred mainly from January to April, and was recorded with relatively high abundances in the Weddell Sea (up to 9.5×10^4 cells l^{-1}). *C. castracanei* forms straight or slightly curved, short to long chains, with the terminal and intercalary setae pointing in the same direction. The apertures are very reduced, centrally constricted, and there are numerous chloroplasts in the cells including the setae. Electron microscopy studies showed that valves are randomly perforated by round poroids, costae on the valve are absent, and an excentric rimoportula is present in every valve of the chain; the setae are circular in cross section at the base, but become four-sided distally. Setae have perpendicular rows of elongate poroids, spines are arranged in spirals along the setae and the tips are very pointed. The intercalary setae are fused together in sibling valves. *Chaetoceros impressus* Jensen *et* Moestrup, recently described from Danish waters, appears to be conspecific with *C. castracanei*, and consequently we propose it as a synonym of the latter. The known distribution of *Chaetoceros castracanei* may be broadened to include Antarctic, subantarctic and Danish waters, and also possibly more temperate regions.

Keywords: Antarctica; *Chaetoceros castracanei*; diatoms; distribution; morphology.

Introduction

The plankton diatom flora in the Antarctic Ocean is not species rich, though highly productive. Despite the high species diversity of the genus *Chaetoceros* Ehrenberg, with more than 175 recognized species and about 400 names cited (Rines and Hargraves 1988, Hasle and Syvertsen 1997), the number of species in this part of the world is limited, compared to temperate, subtropical and tropical areas, where authors have reported an average of 45 species (or taxa) (e.g., Cupp 1943, Hendey 1964, Rines and Hargarves 1988, Hernández-Becerril 1996, Hernández-Becerril and Flores Granados 1998). In the Antarctic, the list includes no more than 25 species (or taxa) (Priddle and Fryxell 1985, Hernández-Becerril et al. 2000). However, it is clear that there is a number of species occurring exclusively in this region, and these forms may be very important in terms of abundance and biomass.

We have been studying the *Chaetoceros* flora from phytoplankton surveys made along the north coast of the Antarctic peninsula, the Weddell Sea and the Gerlache Strait (Hernández-Becerril et al. 2000). *Chaetoceros castracanei* Karsten sometimes appeared in our samples and was occasionally abundant, although mostly uncommon; Hendey (1937) previously found the species to be abundant in Antarctic waters.

Chaetoceros castracanei was described originally by Karsten (Karsten 1905) from Antarctic waters, and he included some detailed illustrations. The species has been reported from the Antarctic by relatively few researchers subsequently (Hendey 1937, Manguin 1960, Hargraves 1968, Priddle and Fryxell 1985). However, the species was also recorded in more temperate or subtropical waters of China (Chu and Kuo 1957). The morphology, taxonomy and distribution of this species have not been studied in detail. Therefore, we herein present a morphological study of this species and discuss some of its possible taxonomic relationships, its environment and its distribution.

Materials and methods

Phytoplankton was sampled from the north coast of the Antarctic peninsula, the Weddell Sea and the Gerlache Strait, in 1985, 1986, 1999, and 2000–2002, during three of the Antarctic oceanographic cruises carried out on board the icebreaker A.R.A. “Almirante Irízar”, in the framework of the project “Argentina for the study of the Austral Atlantic Ocean” (ARGAU). The locations of the fixzed stations are given in Figure 1, and environmental

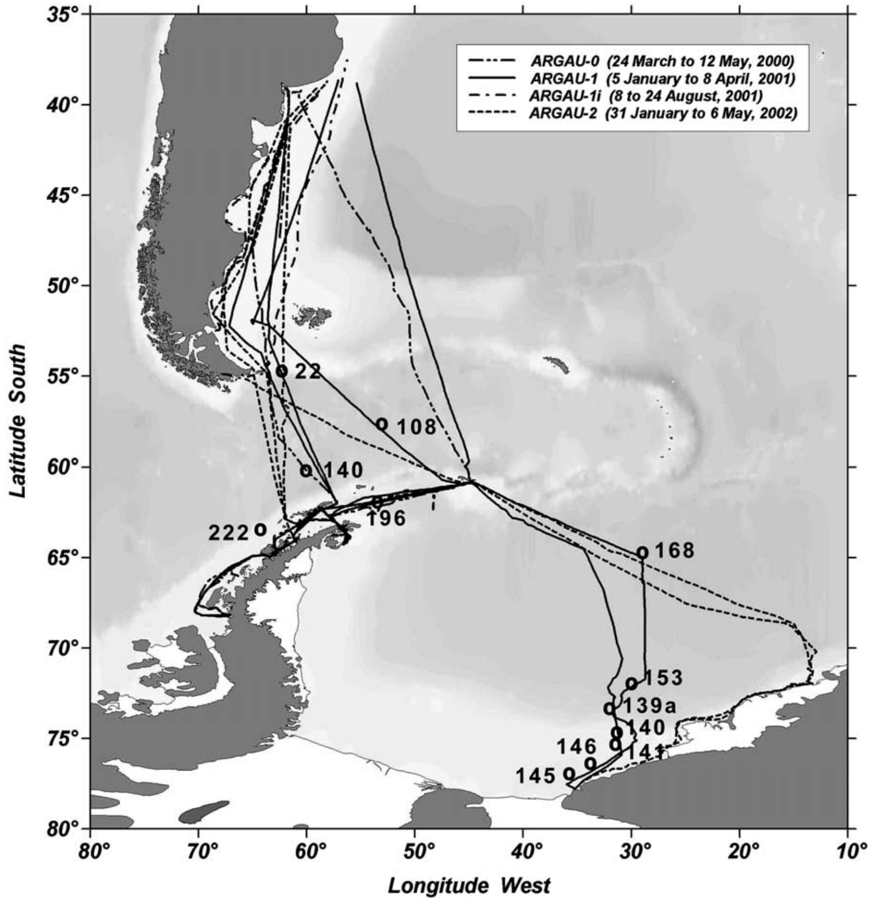


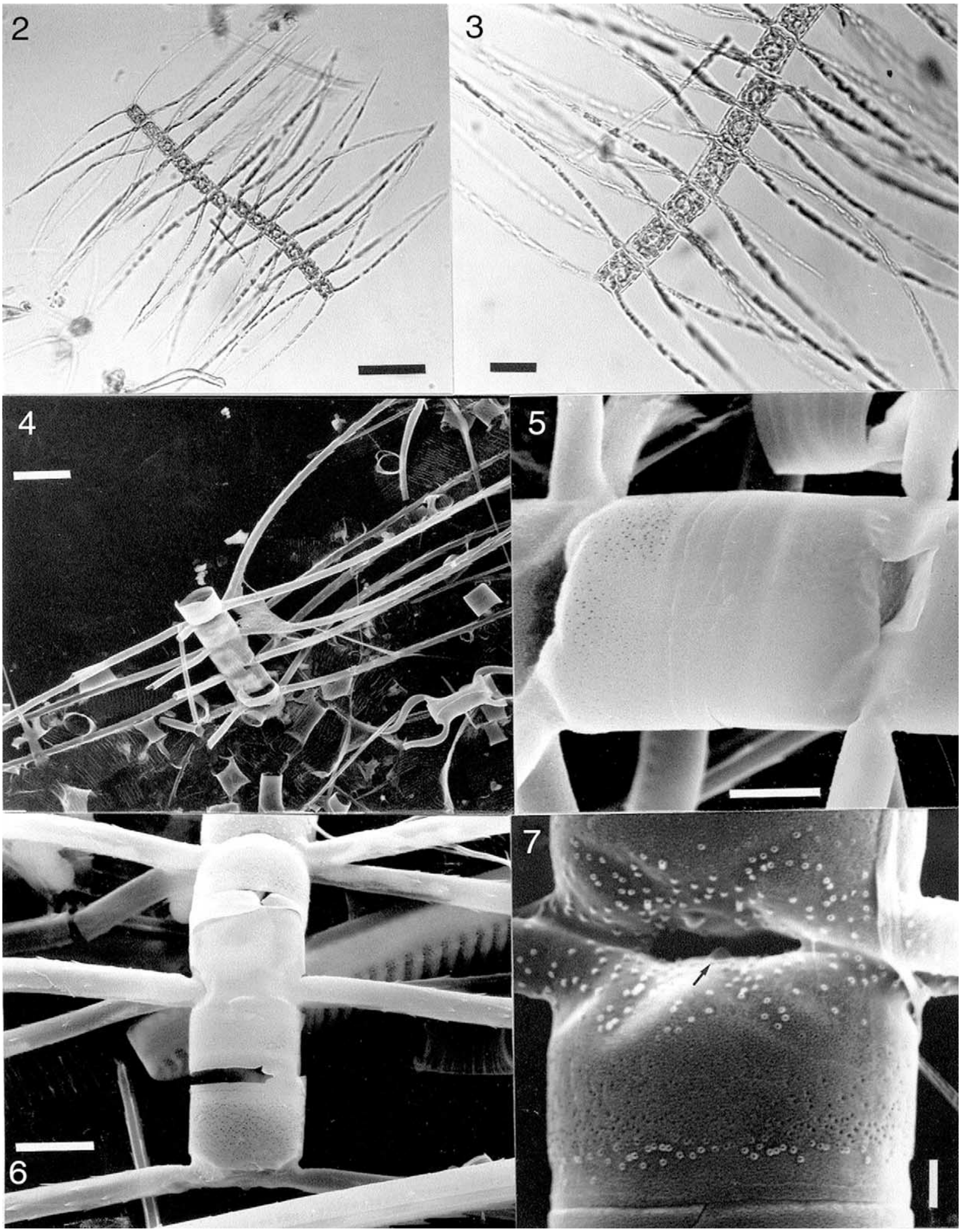
Figure 1 *Chaetoceros castracanei*: tracks of four cruises ARGAU (2000–2002), with locations of stations where specimens of *Chaetoceros castracanei* were found in Antarctic and subantarctic waters.

data are provided in Table 1. Each ARGAU cruise had five legs from January to May (2000–2002), and also in August, 2001. Qualitative samples were taken with a 30 μm mesh net, and quantitative samples were collected from nine depths using a continuous sampling system. Samples were preserved with formalin (4%) and Lugol's solution, respectively.

The preserved net material was treated according to Hasle and Fryxell (1970), and was prepared for light and electron microscopy (LM, EM) according to the proce-

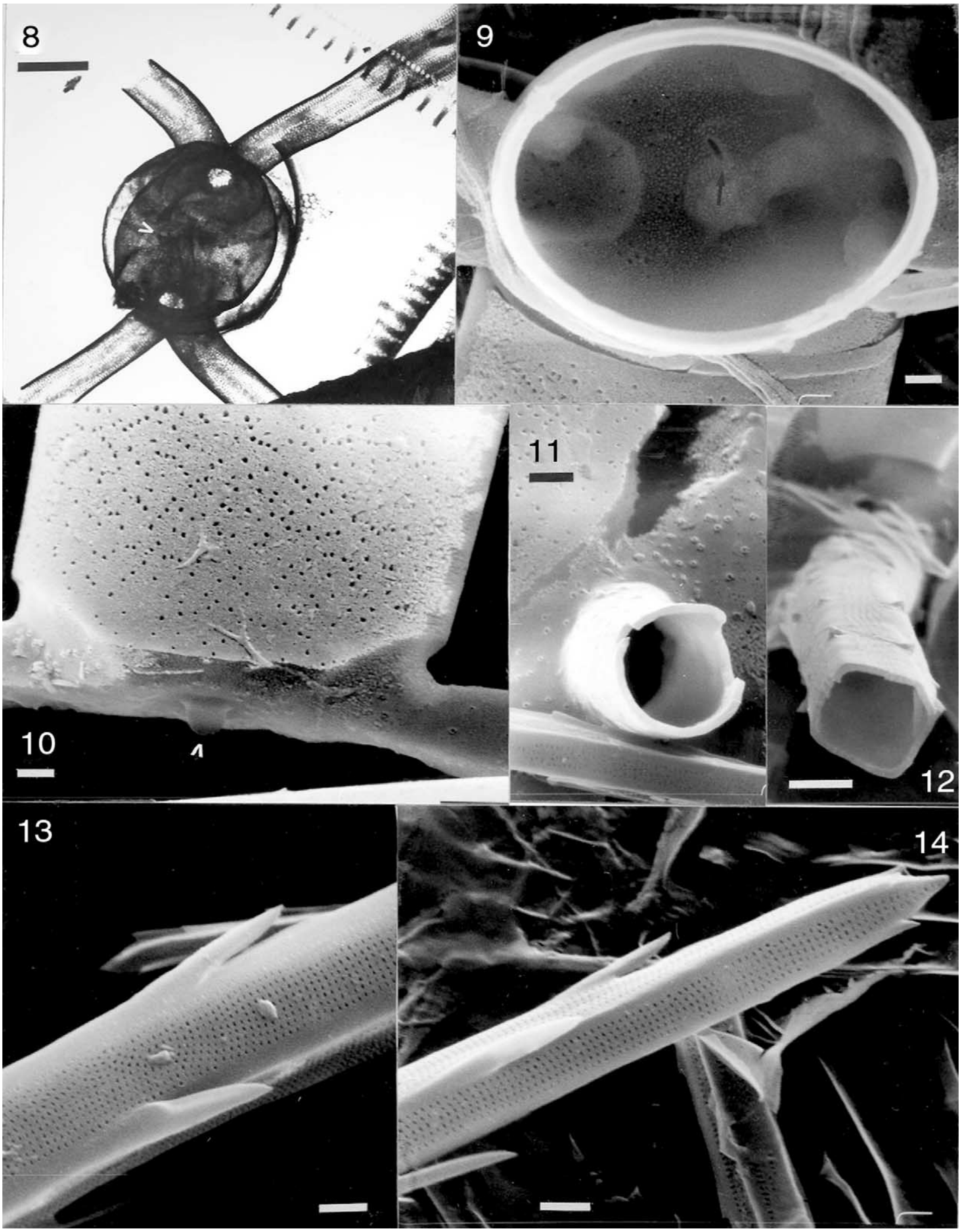
Table 1 *Chaetoceros castracanei*: location of fixed stations and environmental data for three different cruises ARGAU (2000–2002), where specimens of the species were found (dates as day/month/year).

Cruise (date)	Station	Latitude S	Longitude W	Temperature (°C)	Salinity (psu)
ARGAU 0-2000					
04/04/00	140	62° 84.00'	60° 06.00'	1.61	33.87
ARGAU 1-2001					
07/01/01	22	55° 10.21'	47° 32.76'	3.45	33.86
22/02/01	108	58° 52.87'	51° 22.59'	–	–
26/02/01	139a	74° 24.30'	31° 18.56'	0.78	33.73
26/02/01	140	75° 11.05'	31° 05.52'	0.72	33.80
26/02/01	141	75° 56.86'	31° 00.23'	0.69	34.18
27/02/01	145	77° 39.76'	35° 32.84'	1.33	34.19
04/03/01	146	77° 07.72'	34° 48.44'	1.41	34.16
05/04/01	156	73° 13.29'	30° 13.63'	1.76	32.90
08/04/01	168	64° 50.18'	29° 34.40'	0.21	33.70
15/04/01	222	64° 53.86'	64° 28.97'	1.48	33.85
ARGAU 2-2002					
23/03/02	196	54° 38.00'	63° 56.00'	7.84	33.47



Figures 2–7. *Chaetoceros castracanei*: light microscopy (LM) and scanning electron microscopy (SEM).
(2) A complete chain of 12 cells, LM. (3) Terminal portion of the same chain, showing nuclei and chloroplasts (in cell and setae), LM. (4) Part of a chain with 5 cells, SEM. (5) Middle part of a chain, with apertures and girdle bands, SEM. (6) Terminal cell of another chain, SEM. (7) Two sibling valves showing external projections of rimoportulae, one is arrowed, SEM. Scale bars=50 μm (Figure 2), 20 μm (Figures 3, 4), 5 μm (Figures 5, 6), 2 μm (Figure 7).

dures recommended by Ferrario et al. (1995). Quantitative material was analyzed by the Utermöhl method (Lund et al. 1958, Hasle 1978) using an inverted light microscope (Iroscope SI-PH, Mexico City, Mexico). Specimens were examined and photographed using a (Wild M20, Heerbrugg, Switzerland) light microscope, equipped with a Wild camera, and a (SEM JEOL JSMT 100, Tokyo, Japan) scanning electron microscope. A JEOL 1200 EX (Tokyo, Japan) transmission electron microscope was used for transmission electron microscopy (TEM). Mate-



Figures 8–14. *Chaetoceros castracanei*: transmission microscopy (TEM) and scanning electron microscopy (SEM). (8) Two sibling valves in valve view, an arrowhead points to the rimoportula, TEM. (9) Internal view of an intercalary valve with the slit of the eccentric rimoportula (arrowed), SEM. (10) Terminal valve showing external projection of the rimoportula (with an arrowhead), SEM. (11) Base of intercalary seta just after fusion with sibling seta, SEM. (12) Cross-section of intercalary seta, SEM. (13) Middle part of seta, showing large spines, SEM. (14) Tip of same seta, with smaller spines around the tip, SEM. Scale bars=2 μm (Figures 8, 11–14), 1 μm (Figures 9–10).

rial for TEM was prepared by micropipetting small aliquots of treated material onto formvar-coated grids and then rinsed three times in distilled water. Preserved material was deposited in the collection of Diatomeas Argentinas at the División Ficología, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata, La Plata, Argentina.

The terminology adopted herein follows the proposals by Ross et al. (1979), Rines and Hargarves (1988), and Hernández-Becerril (1996).

Table 2 Comparison of morphological data and environmental conditions of occurrence for *Chaetoceros castracanei* and *C. impressus*.

Species	Apical axis	Pervalvar axis	Aperture	Valve	Rimo	Setae	Environmental conditions
C. castracanei (chains of 3–12 cells)[a]	8.5–20[a] 20–25[b] 12–26[c] 10.5–23[d] ca. 15[e]	12–17[a] ? ? 11–17[d] ?	Reduced, centrally constricted	Perforated by pores, no costae	Short projection, slightly eccentric	Rows of poroids, spines in spiral; CSP: round, CSD: four-sided	0.21–7.84°C, 32.9–34.2 psu
C. impressus (chains of 4–10 cells)[f]	17–28[f]	?	Short, narrow, sometimes absent	Poroid	Outside short, small structure; central (?)*	Rows of poroids between silica ridges, spines in spiral; CSP: round, CSD: four-sided	Low salinity

CSD=cross section distal; CSP=cross section proximal. [a] this paper; [b] Hendey (1937); [c] Hargraves (1968); [d] Fryxell and Priddle (1985); [e]Hasle and Syversten (1997); [f]Jensen and Moestrup (1998); *Jensen and Moestrup's (1998) fig. 24 shows a rather eccentric rimoportula.

Results

Chaetoceros castracanei Karsten (Figures 2–14)

Original reference: Karsten (1905), p. 116, pl. 15, figs. 1, 1a, 1b. Synonym: *Chaetoceros impressus* Jensen *et* Moestrup; Jensen and Moestrup (1998), p. 17, figs 19–29.

Description

Specimens of this species form robust, straight or slightly curved chains of cells, which are short, medium-sized or longer, with 3–12 cells per chain chain (Figures 2–4). In broad girdle view, the terminal and intercalary setae are directed in the same direction, and there are numerous chloroplasts in cells and setae (Figures 2, 3). The apertures are very reduced and centrally constricted. The cells are rectangular or nearly square in girdle view, with the apical axis being slightly longer, whereas in valve view the cells are elliptical (Figures 2, 3, 8). The valve face is nearly flat, the valve mantle is high, and there are constrictions at the girdle zone. The setae arise from the corners of the valves and are almost straight in girdle view, perpendicular to the chain axis. Sibling setae diverge at an angle of approximately 30° from each other in valve view (Figures 2–6). The setae have spines along their length (Figures 4, 6).

Electron microscopy reveals heavily silicified valves, randomly perforated by round poroids, and lacking costae (Figures 5, 7, 8, 10). Every valve in the chain possesses an eccentric rimoportula (Figures 7–9). Scattered granules also occur on the valve face and on part of the valve mantle (Figures 7, 11). The poles of the valves have elevations at the bases of the setae (Figures 5, 7). The outer rimoportula has a short projection, with an internal slit orientated obliquely or parallel to the apical axis (Figures 7–9). The rimoportula of terminal valves has a large external projection (Figure 10) but only a simple slit on the inner face of the valve (Figure 9).

Immediately after arising from the valve, the intercalary setae of sibling valves are fused (Figures 5–7). The setae are circular in cross section at their bases, but become four-sided distally (Figures 11, 12). In the seta wall, there are perpendicular rows of elongate poroids, and strong spines arranged in spirals along the setae (Figures 12–14). The tip of each seta is pointed and around it there are also smaller spines (Figure 14).

Dimensions: cells measured 8.5–20 μm in the apical axis, 12–17 μm in the pervalvar axis, 1.7–2.5 μm in the aperture, setae were 130–155 μm long, 2.8 μm wide at the very base, had a maximum width of 6.5 μm in the middle part, and were 3.9 μm wide at the tip.

Abundance and distribution

The estimated density of the species, ranged from less than 100 cells l^{-1} in most locations, up to 2.5×10^4 cells l^{-1} in February, 2001 (Station 141: 75° 56.86' S, 31° 00.23' W, Table 1), and 9.5×10^4 cells l^{-1} in March, 2001 (Station 146: 77° 07.72' S, 34° 48.44' W, Table 1). However, *Chaetoceros castracanei* was not usually very abundant in our samples.

The species is distributed south from the Antarctic convergence, mainly in the Weddell Sea and north of the Antarctic peninsula, from January to April. *Chaetoceros castracanei* was found at temperatures ranging from 0.21–7.84°C, and salinity from 32.9–34.2 psu.

Discussion

Morphology

All details described in this paper for *Chaetoceros castracanei* have been shown to characterize most species of the subgenus *Chaetoceros* (*Phaeoceros*), one of the three subgenera of *Chaetoceros* (Hustedt 1930, Cupp 1943, Evensen and Hasle 1975, Rines and Hargraves 1988, Hernández-Becerril 1993). Species of the subgenus *Chaetoceros* are usually robust, with large appendages (setae, external projection of rimoportulae), possess at least one rimoportula per valve, and have chloroplasts in the cells and setae. Therefore, it is clear that *C. castracanei* belongs to this subgenus.

No unique morphological features were encountered in *Chaetoceros castracanei*, but the species appears easily recognizable and characteristic in routine samples, mainly due to the shape of the chains and cells. Descriptions previously provided by Karsten (1905), Hendey (1937), Manguin (1960), Hargraves (1968), Priddle and Fryxell (1985), and Hasle and Syvertsen (1997) agree well with those given herein. This is the first study of the species by EM (e.g., Gaul et al. 1993).

We did not find any significant morphological variability in the species. The most important morphological variations were the length of complete, unbroken chains, from very short chains containing only three cells to longer chains of 12 cells, and the slight curvature of the chains. The production of short chains is a possible mechanism of divisions of chains in the genus *Chaetoceros* (Rines and Boonruang 1995). Torsion of chains for this species was shown by Chu and Kuo (1957), but was not detected in our material.

We did not find any resting stages, such as resting spores, or any indication of sexual stages (formation of gametes, etc.). Specimens of this species were slightly smaller than those recorded by Hendey (1937), but agree with other reports (Priddle and Fryxell 1985, Hasle and Syvertsen 1997) (Table 2).

Taxonomic relationships

Hendey (1937) previously placed this species in the section *Borealia*, one of the six into which the subgenus *Chaetoceros* is divided (e.g., Hustedt 1930, Cupp 1943, Rines and Hargraves 1988, Hernández-Becerril 1996, 1999, Hernández-Becerril and Flores Granados 1998, Rines and Theriot 2003). We believe that *Chaetoceros castracanei* possibly belongs in this section because it shares many characteristics with other members of the section *Borealia*, in particular the terminal setae which are not distinctly differentiated from intercalary setae and reduced apertures (shorter than the width of the pervalvar axis). Infrageneric classification of the genus *Chaetoceros* needs to be revised (Rines and Hargraves 1988, Rines and Theriot 2003).

We have found that *Chaetoceros impressus* Jensen *et* Moestrup (Jensen and Moestrup 1998) recently described from Danish waters, is identical to, and therefore conspecific with, *C. castracanei*. The shape of the chains and cells is the same as many specimens encountered from Antarctic waters in our study. Furthermore, details of the valves, location of the rimoportula (Jensen and Moestrup 1998 regarded this structure as central) and setae (with poroids and large spines, proximal and distal cross sections) of *Chaetoceros impressus* are basically similar to those of *C. castracanei* (Table 2). Consequently, we propose that *Chaetoceros impressus* as a synonym for *Chaetoceros castracanei*. Jensen and Moestrup (1998) observed a "male gamete formation", a characteristic not seen in our study. A comparison of morphological data and environmental conditions of both species is provided in Table 2.

Chaetoceros danicus Cleve is also potentially closely related to *C. castracanei*. Jensen and Moestrup (1998) discussed the morphological similarities between *C. impressus* and *C. danicus*, but mentioned that the former species "is readily distinguished by cell size and the characteristic setae". They also noted that the setae are coarser in *C. impressus* than in *C. danicus*. Therefore, *Chaetoceros danicus* can be regarded as the most closely related species to *C. castracanei*.

Habitat and distribution

There are few environmental data to accompany the distribution records of *Chaetoceros castracanei*. Hendey (1937) provided water temperature, salinity and pH measurements for stations where specimens of *C. castracanei* were reported. He found that specimens collected from 60°32'–62°21' S, and 60°36'–62°42' W, occurred at temperatures ranging from 0.10–0.45°C, salinity 33.78–34.04 psu, and pH 7.95–8.4. Other data were provided by Hargraves (1968), who found the species at temperatures of −0.5 and 5.3°C, and salinities of 34–34.2 psu. No environmental variables were given in Chu and Kuo's (1957) paper, and this is the only report of the species in a more temperate region (China).

All previously available data are similar to those measured in our study, namely that *C. castracanei* appeared at temperatures of 0.21–7.84°C and salinities of 32.9–34.2 psu. No environmental data were available for the occurrence of the species *Chaetoceros impressus*, in Denmark, apart from "low salinity" (Jensen and Moestrup 1998).

Historically, the known distribution of *Chaetoceros castracanei* has been restricted to Antarctic waters, and according to Hendey (1937), the species is neritic. This distribution may need to be extended to the subantarctic circle and to Danish waters, especially if the conspecificity of *Chaetoceros castracanei* and *Chaetoceros impressus* is proven. The presence of the species in more temperate (or even subtropical) waters of China (Chu and Kuo 1957) is still a matter for further discussion, but it means that the species may also be more widely distributed.

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