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Fallacia fawensis sp. nov., a new brackish water diatom (Bacillariophyceae) from Southern Iraq

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Abstract

The diatom genus *Fallacia* includes species having a conopeum which is a perforated thin sheath of silica lying along the apical axis on the external valve face and a hyaline lateral area in the internal valve face. In surveying the benthic diatoms of Basra, a new small brackish water species, *Fallacia fawensis* was found associated with fine-grained substrata on the western bank of Shatt Al–Arab River, Southern Iraq. This epipelic species is described based on light and scanning electron microscopy and characterized by having a porous conopeum covering the area between raphe sterna and mantle, narrow elongated marginal striae, and a structure similar to lateral hyaline areas in the valve internal side. The terminal raphe endings on the external valve face, below valve apex, the raphe sternum inner margins come close to each other, blocking raphe canal but leaving a lacuna-like thin groove for connection with the deflected upper part of the open raphe canal. These features separated this species from allied taxa of the genus and also from closely related genera, *Pseudofallacia* and *Germaniella*. Notes on the ecology and distribution of the new species as well as the associated diatom taxa are provided.

Keywords: Bacillariophycea, Epipelic, Iraq, New species, Shatt Al–Arab River

Introduction

Fallacia Stickle & D.G.Mann (in Round *et al.* 1990: 667) is a widely distributed benthic diatom genus inhabiting marine and brackish water intertidal habitats (Sabbe *et al*. 1999; Witkowski et al. 2000). According to Algaebase (Guiry & Guiry 2020), *Fallacia* encompasses 115 taxa distributed from the tropics to the polar regions. The first record of a member of this genus goes back to the 19th century and appeared in the work of Kützing Species Algarum under the name *Navicula pygmaea* (Kützing 1849: 77). The separation of *Fallacia* from *Navicula* Bory (1822) was based on distinctive valve structure named conopeum beside a hyaline lateral areas on both sides of the axial area (lateral sterna). The conopeum is a perforated thin sheath of silica lying along the apical axis on the external valve face and completely or partially covering the striae (Garcia 2003). This structure, however, is invisible in light microscope (LM) and requires scanning electron microscope (SEM) to reveals its shape and position.

The majority of *Fallacia* taxa are of small size, mostly not exceeding 20 µm (Li *et al*. 2015). This posed a problem in the identification of the species, particularly in routine monitoring of diatom associations in inland water impoundments (Sabbe *et al*. 1999). The two most significant characteristic features of *Fallacia*, the perforated conopeum and the lateral sterna, are remarkably variable among its taxa, particularly the lateral sterna. Based on the variability of the later feature, a new genus was erected; *Pseudofallacia* Liu, Kociolek & Wang (2012: 624) to which six species of *Fallacia* were transferred. According to Li *et al*. (2019), it is unclear if the variation in the lateral sterna would justify the erection of a new genus and a phylogenetic analysis is highly required to elaborate *Fallacia* species delineation. The wide variability in the *Fallacia* species morphological features was discussed by Sabbe *et al*. (1999) and Garcia (2003), therefore molecular investigations are required although such task would not always be feasible especially with rare and small species.

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In the vast brackish wetlands of Southern Iraq which are characterized by a subtropical climate, only three species of *Fallacia* were reported including *Fallacia florinae* (Möller) Witkowski (1993: 215), *Fallacia oculiformis* (Hustedt) D.G.Mann (in Round *et al*. 1990: 669) and *Fallacia pygmaea* (Kützing) Stickle & D.G.Mann (in Round *et al*. 1990: 668)(Al-Handal 2009; Al-Handal & Al-Shaheen 2019). Two additional marine species were reported from the neighbouring coastal water of Kuwait: *Fallacia nummularia* (Greville) D.G.Mann (1990: 669) and *Fallacia schoemaniana* (Foged) Witkowski, Lange–Bertalot & Metzeltin (2000: 213) (Al-Yamani & Saburova 2011). The difficulty to identify small sized *Fallacia* species creates taxonomic confusion in LM which may have lead authors investigating diatoms in this region to consider these species as *Navicula* spp. (e.g. Hinton & Maulood 1980; Maulood *et al*. 1981).

The present work is part of a wide survey of the diatom flora of Southern Iraq. In sediment samples collected from the southern reaches of Shatt Al-Arab River, we found a species that appeared in LM similar to *Fallacia* based on its faint lateral hyaline areas and arched raphe sterna. SEM observation revealed a perforated conopeum covering external valve face which allowed placing the species into *Fallacia*. The valve ultrastructure of the newly found species did not match any of the published *Fallacia* taxa which lead us to describe it as new to science.

Material and methods

Study site

The Shatt Al–Arab River (30°18′ N, 48° 53′ E) stretches for 200 km in Southern Iraq and covering a basin area of 145000 km^2. The River is formed by the junction of the Tigris and Euphrates at Qurna city, 60 km north of Basra, and discharges into the Arabian Gulf. Along its course, the River′s width varies between 250 m near its mouth to 800 m at the south with a depth ranging from 7 to 14 m, depending on the tidal cycle of the Arabian Gulf (Mohamed & Abood 2017). Owing to the remarkable decrease of freshwater discharge from the Tigris and Euphrates, seawater from of the Gulf may proceed up to 80 km upstream during high tide (Abdullah *et al*. 2016). Such intrusion of seawater created a salinization problem in Shatt Al–Arab River turning it into a weakly to strongly brackish water habitat. Both banks of the River are inhabited by aquatic vegetation such as reed, rushes, and papyrus. The climate of the region is subtropical, hot, and arid with limited level of precipitation.

Sampling and Methods

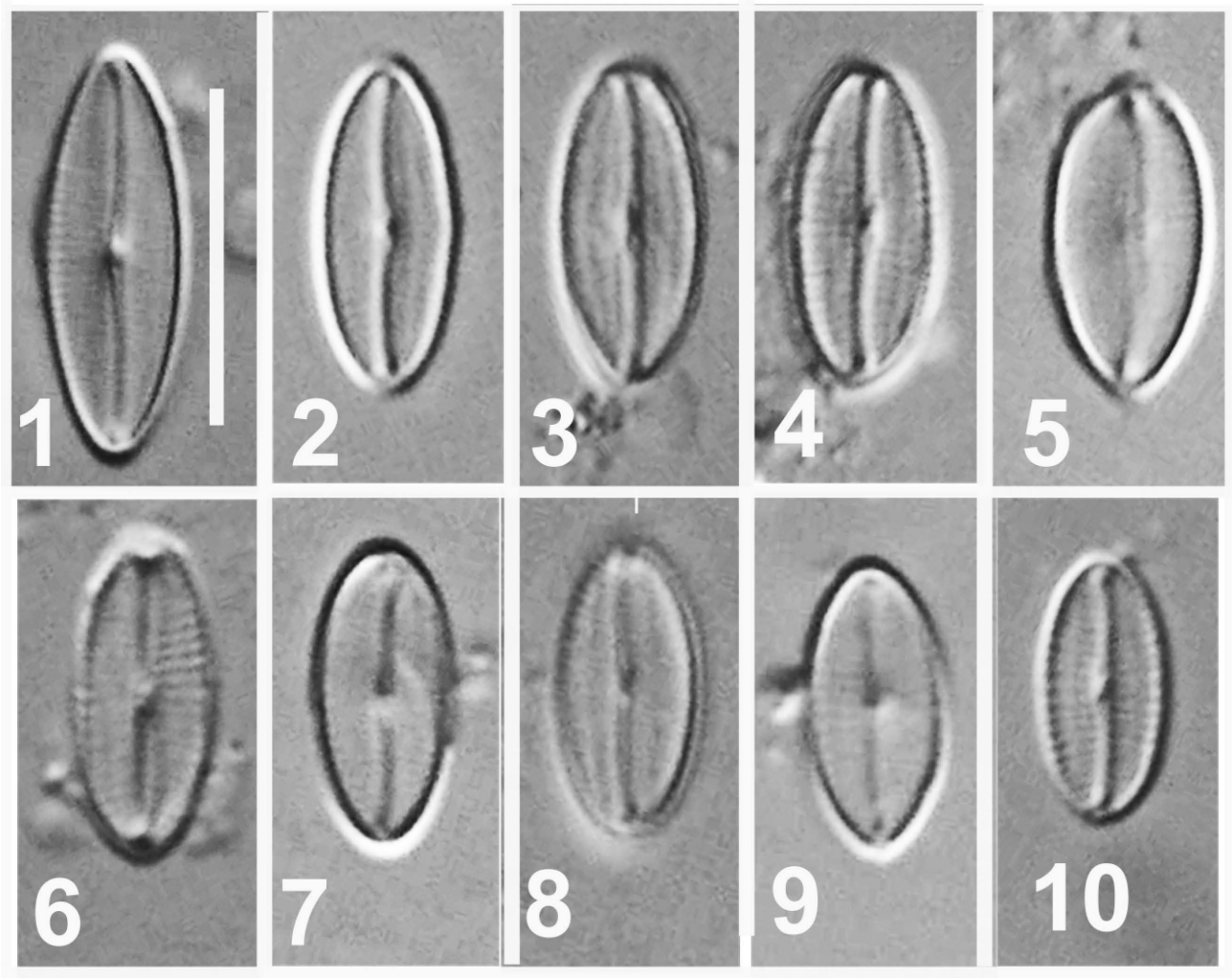
Samples were collected during August 2020 from the western bank of Shatt Al-Arab River at the Faw town (29° 58′ 22′′ N, 48° 28′ 14′′ E). This area is covered with seawater during high tide and sediment become exposed during low tide. The river bank at this area is formed of clay, silt and fragments of mollusc's shells with patches of aquatic plants covering the sediment. Samples containing diatoms were obtained by scrapping the upper 2 mm of the muddy sediment at various spots. Samples were kept in 15 ml plastic vials, covered with few ml of the river water and preserved in 4% formalin. For the preparation of permanent mounts, diatom material was first washed with deionized water to remove salts and then cleaned by boiling in 35% hydrogen peroxide. Few drops of 50% hydrochloric acid were added to remove the carbonates. After several rinses with deionized water, drops of the cleaned diatom suspension were left to dry in ambient temperature on a cover slip and then mounted in Naphrax®. Light microscope images were taken using a Zeiss Axioimager 2 microscope equipped with Cannon PowerShot G6 digital camera (LM, Carl Zeiss AB) with differential interference contrast objectives (Department of Biological and Environmental Sciences, University of Gothenburg, Sweden). For SEM observations, the cleaned diatom aliquot was filtered on 1 µm Nucleopore Whatman filter and left to dry on an aluminium stub covered with conductive and adhesive black carbon disks before coating with gold palladium alloy. A Zeiss Ultra 55 FEG SEM (Chalmers University, Sweden) was used for valve ultrastructure examination and imaging. Terminology of valve structure description used in this article is that of Ross *et al*. (1979) and Round *et al*. (1990).

Water temperature at time of collection was measured by a mercury thermometer and salinity was determined using a portable conductivity meter (WTW Cond 3110, Germany). Relative abundance (RA) of *F. fawensis* and the associated taxa was done by counting 400 valves across the slide according to the formula: RA % = n*i*/*N* * 100, where n*i* refers to the number of individuals of taxa *i* in the sample and *N* refers to the total number of diatoms counted in the sample.

Results

Division Bacillariophyta
Class Bacillariophyceae
Order Naviculales
Family Sellaphoraceae
Genus *Fallacia* Stickle & D.G.Mann

Fallacia fawensis Al–Handal, Al–Shaheen, Al–Saedy & Wulff sp. nov.
(Figs LM 1–10, SEM 11-19)

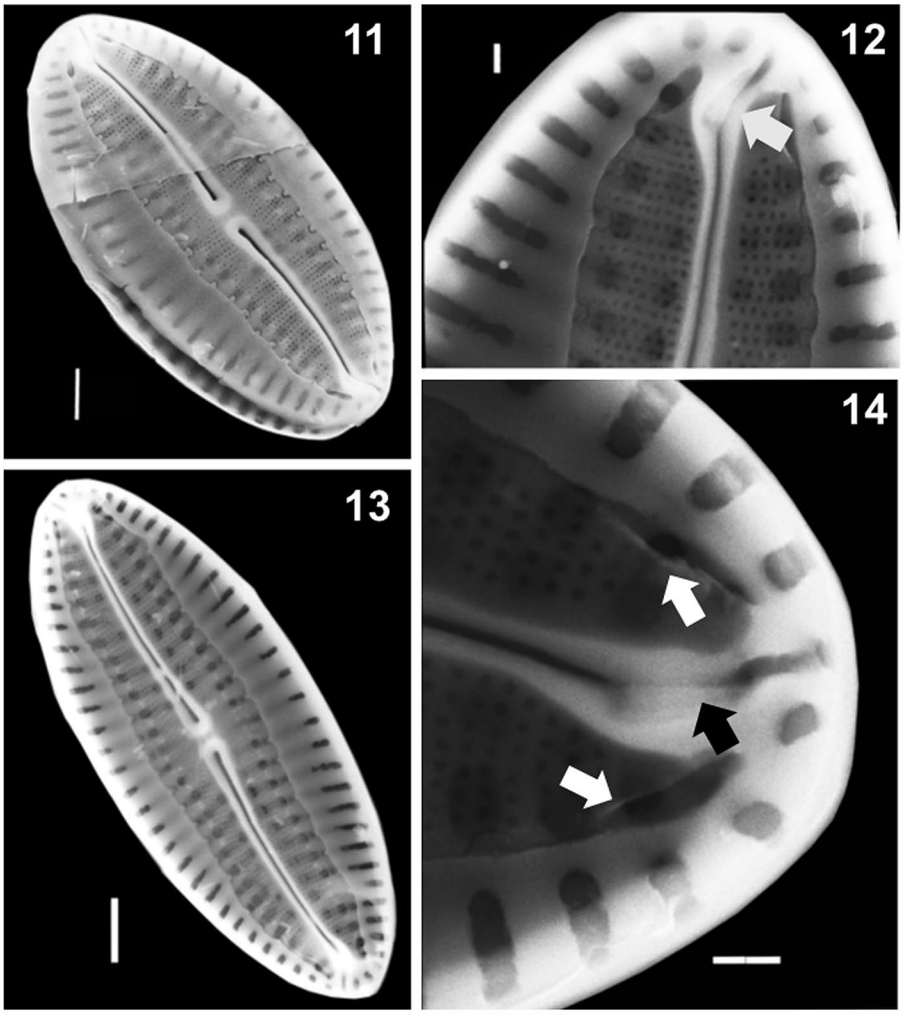


FIGURES 1–10: *Fallacia fawensis* Al-Handal, Al-Shaheen, Al-Saedy & Wulff sp. nov., LM images of the type material from Shatt Al–Arab River, Southern Iraq showing valve size and outline variation. Scale bar = 10 μm.

Description:
LM observation (Figs 1–10): Cells solitary. Valves are linear lanceolate to elliptical with rounded apices, 7.7–12.3 μm long and 3.5–5.1 μm wide (n=32). Striae are very fine and difficult to resolve in LM. In the larger specimens and in differential interphase contrast (DIC) observation, striae in the middle part of the valve may appear distinctly parallel (Fig. 10). The lateral hyaline areas are indistinct or appear faint in some specimens. The central area is very small, axial area is indistinct. Raphe branches are weakly arched towards the primary side of the valve, proximal raphe endings appear slightly bent.

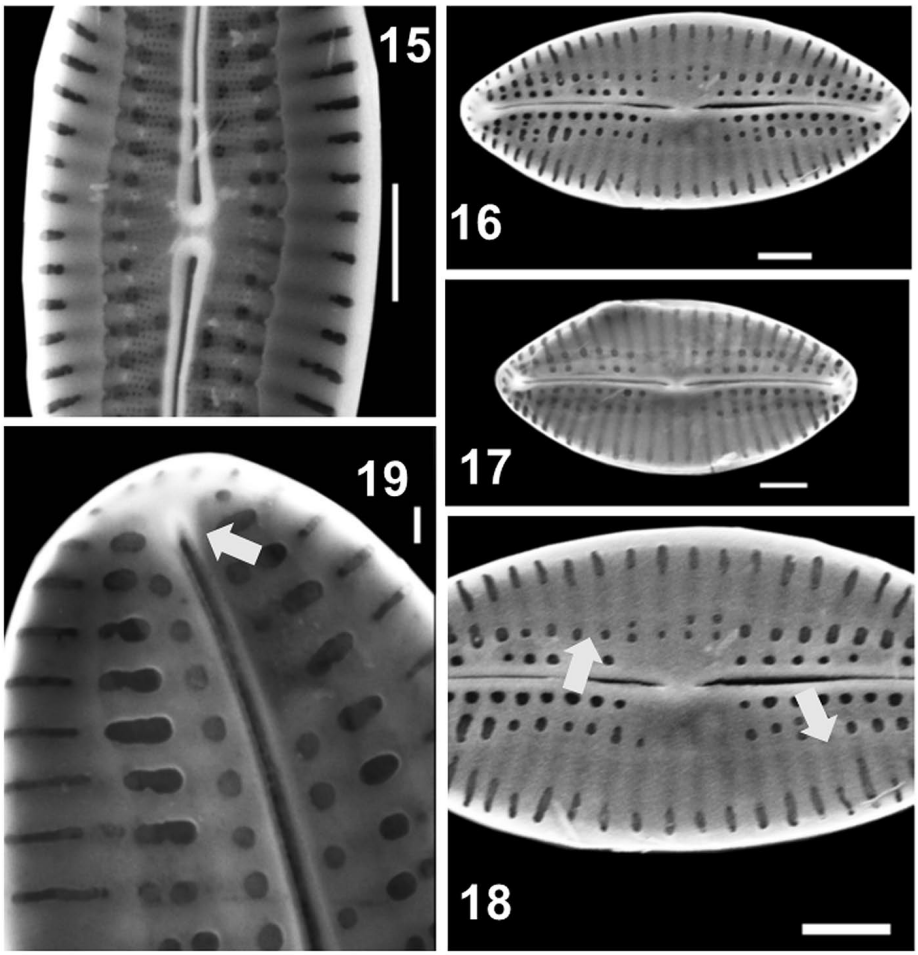
SEM observation (Figs 11–19): Externally, the valve surface is covered with a porous conopeum which extends from the raphe sterna to shortly before valve mantle (Figs 11–14). The conopeum pores are rounded and arranged in transapical lines which appear mostly equidistant. The valve mantle extends to half the distance between valve margin and raphe canal and possesses very small finger–like protrusions which correspond to a row of areolae under the

conopeum (Figs 11,15). Raphe sterna are slightly arched, becoming wider around the proximal endings and slightly raised above valve surface (Figs 11,12,15). Raphe proximal endings are gradually widening towards the central area (Fig. 15). Raphe distal endings are deflected to the same side and extend to the valve mantle, surrounded on both sides by two narrow slits (Figs 12,14 white arrows). Before reaching the valve apex, inner margins of raphe sternum come close to each other leaving a very narrow lacuna–like groove through which raphe is connected to the deflected terminal part of the raphe on the mantle (Fig. 14, black arrow). Striae are uniseriate, 26–34 in 10 µm, composed of three longitudinal rows of areolae (Fig. 12). The outer row under the mantle is formed of elongated areolae and the two inner rows are formed of equidistant rounded areolae (Fig. 12). The areolae in the row on both sides of the raphe are terminated before raphe proximal endings leaving a quadrangular central area (Fig. 15). Internally, raphe proximal endings are simple and separated by a slightly elevated and narrow central nodule (Figs 16–18). The distal endings are terminated by a shallow helictoglossae, slightly before valve margin (Fig.19). In all specimens examined, the lateral hyaline areas are not truly hyaline and devoted of striae but are formed of lyrate silica flaps covering the areolae and not connected across the central area (Figs. 16–18). In some specimens, these silica flaps are rather thin where areolae can be seen underneath (Fig. 18, arrows). The inner row of areolae adjacent to raphe is formed of rounded areolae (Figs 18,19), while the outer row is formed of thin and elongated areolae (Fig. 19).



FIGURES 11–14: *Fallacia fawensis* Al-Handal, Al-Shaheen, Al-Saedy & Wulff sp. nov. Figs 11,13 SEM external valve face showing raphe sterna and valve mantle. Fig. 12 SEM upper part of the valve external face exhibiting the narrowing raphe sterna near valve apex (arrow). Fig. 14 SEM detail of the external valve face showing structure of the conopeum and the polar elongated pores of the lyre canal (arrows). Scale bars = 1 µm for Figs 11,13, 0.2 µm for Fig. 12, 0.4 µm for Fig. 14.

Holotype: Permanent slide and material containing frustules of *Fallacia fawensis* sp. nov., are deposited in the Botanischer Garten und Botanischer Museum (BGBM), Berlin, Germany under accession XXX (holotype is illustrated in Figs 1,10).



FIGURES 15–19: *Fallacia fawensis* Al-Handal, Al-Shaheen, Al-Saedy & Wulff sp. nov. Fig. 15 SEM middle part of the external valve face showing proximal raphe sterna and endings. Figs 16,17 SEM internal valve face. Fig. 18 SEM internal valve face showing the thin silica flaps covering parts of the elongated striae and appear as lateral areas. Fig. 19 SEM upper part of internal valve face showing distal raphe ending on helictoglossa. Scale bars = 1 μm for Figs 15–18, 0.2 μm for Fig 19.

Type locality: Faw town, western bank of the Shatt Al–Arab River, Southern Iraq (29º 58′ 22′′ N, 48º 28′ 14′′ E).

Etymology: The epithet *fawensis* refers to the Faw town in southern Iraq where this species was first encountered.

Ecology: *Fallacia fawensis* was a rare epipelic species within the diatom community found on the muddy shores of Shatt Al–Arab River at Faw town, Southern Iraq. Salinity at time of collection was 5.2 and water temperature 38°C. On all slides prepared from the samples, *F. fawensis* constituted an average of 1.2% of the other taxa and was associated with some common taxa including *Entomoneis corrugata* (Giffen) Witkowski, Lange–Bertalot & Metzelten (2000:198)(3.75%), *Halamphora* sp. (4.5%), *Nitzschia clausii* Hanitzsch (1860: 40)(7.3 %), *Nitzschia palea* (Kützing) W.Smith (1856:89) (9.5%) and *Petrodictyon gemma* (Ehrenberg) D.G.Mann (in Round et al. 1990:638) (7.5%). *Fallacia fawensis* was not encountered in samples collected from northern parts of Shatt Al–Arab River.

Discussion

Because of its small size, *Fallacia fawensis* appear in LM similar to a number of allied species that possess similar valve outline and morphology. These include *Fallacia cassubiae* Witkowski (1991: 403), *Fallacia florinae* (Möller) Witkowski (1993: 215), *Fallacia marginopunctata* Sabbe & Vyverman (1999: 15) and *Pseudofallacia arenaria* (Sabbe & Vyverman) Liu, Kociolek & Wang (2012: 625). A comparison of morphological and structural features between *Fallacia fawensis* and these taxa is provided in Table 1.

In SEM, *Fallacia fawensis* could be easily distinguished from other small sized *Fallacia* by the structure of the terminal raphe endings on the external valve face where just below valve apex the raphe sternum inner margins come close to each other, blocking raphe canal but leaving a lacuna-like thin groove for connection with the deflected upper part of the open raphe canal (Figs 12,14). Another separating feature is the silica flaps that covers parts of the striae and appear as lateral hyaline areas.

According to Sabbe *et al*. (1999), the main characteristic features separating *Fallacia* from other naviculoid diatoms is the combination of hyaline lateral areas on both sides of the raphe sterna and a porous conopeum which may or may not cover the entire external valve surface. Although *Fallacia fawensis* is lacking a true lateral hyaline areas, it is placed in the genus for having a porous conopeum that is not covering the whole valve on the external vale surface. The absence of lateral hyaline areas is not uncommon and was observed in *Fallacia tenera* (Sabbe *et al*. 1999). However, thin silica flaps that cover the striae in the inner valve face have not been reported in *Fallacia*, instead areolae might be found inside the hyaline areas (Witkowski 1991,1993; Sabbe *et al*. 1999; Witkowski *et al*. 2000; Garcia 2003; Procopiak & Fernandes 2003; Li *et al*. 2014, 2015, 2019; Genkal & Yarushina 2017; Stancheva & Manoylov 2018).

Fallacia fawensis has striae composed of three rows of areolae, the outer one in the valve margin on both valve faces as well as on the mantle is formed of thin elongated areolae (Figs 12,13,19). This feature is not common in the genus and may only found in few species such *Fallacia florinae* Witkowski (1993: 215) and *Fallacia marginopunctata* Sabbe & Vyverman (1999:15) but these species differ from *Fallacia fawensis* in having shorter marginal areolae besides a number of other features (Table 1). Elongated areolae are most commonly found in the *Fallacia* taxa which were transferred to *Pseudofallacia* such as *P. occulata* and *P. losevae* (Lange–Bertalot, Genkal & Vechov) Liu, Kociolek & Wang (2012: 625).

Based on the lyre canal, *Fallacia* species are categorized into two groups, the first possesses a lyre canal that often open near the poles with elongated slit-like or rounded pores such as in *Fallacia pygmaea* (Kützing) Stickle & D.G.Mann (Round *et al*. 1990: 668) and *Fallacia forcipata* (Greville) Stickle & D.G.Mann (Round *et al*. 1990: 668). The second group do not have this feature and are mostly freshwater species as in *Fallacia lenzii* Lange-Bertalot (in Werum & Lange-Bertalot 2004:159), *Fallacia scaldensis* Sabbe & Muylaert (Sabbe *et al*. 1999:18) and others. In *Fallacia fawensis*, the lyre canal is not distinct and seem to be depressed beneath the inner mantle margin and open near the poles with narrowly elongated pores (Fig. 14, white arrows). Therefore this species belong to group one of the *Fallacia* taxa.

Since its separation from *Navicula* (Round *et al*. 1990), *Fallacia* appeared to be taxonomically problematic where its characteristic features: conopeum, lyre and lateral hyaline areas, the latter varies in structure and by presence or absence. Based on such differences, two new genera were erected from *Fallacia*, *Pseudofallacia* and *Germainiella* Metzeltin, Lange–Bertalot & García-Rodriguez (2005:75). Because of the very small size and rarity of the species belonging to the latter two genera, it is rather difficult to culture their species for molecular investigation to verify there distinct entities. The validity of transferring some *Fallacia* species to these genera based on morphometric narrow differences remains questionable.

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