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Synedropsis abuflosensis sp. nov., a new araphid diatom (Bacillariophyceae) from the Shatt Al-Arab River, Southern Iraq

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ABSTRACT

Synedropsis abuflosensis sp. nov. is the third species of the genus recorded from a sub-tropical brackish water habitat as opposed to a polar distribution. This species is differentiated from others in the genus by having a different number of slits in the apical slit field at opposite ends of the valve (i.e., 4 at the end possessing a rimoportula versus 5 at the end lacking a rimoportula), an apically oriented rimoportula and 3-4 non-porous cingular bands. Its habitat is different than that of all known *Synedropsis* Hasle, Medlin & Syvertsen species as it is either benthic or epiphytic in algal mats rather than planktonic or associated with sea ice. The new species was found in waters with a conductivity of 7.1 µS $^{cm-1}$ (salinity 3.3 psu) and a temperature of 33 °C. Morphological characters of the new species are described based on light and scanning electron microscopy observations. A comparison of *S. abuflosensis* sp. nov. with morphologically similar species is provided.

KEY WORDS
araphid diatom,
Fragilariaceae,
Iraq,
Shatt Al-Arab River,
Synedropsis,
new species.

RÉSUMÉ

Synedropsis abuflosensis *sp. nov., une nouvelle diatomée araphide (Bacillariophyceae) de la rivière Shatt Al-Arab, au sud de l'Irak.*

Synedropsis abuflosensis sp. nov. est la troisième espèce du genre décrite inféodée à un habitat subtropical d'eau saumâtre par opposition à une distribution polaire. Cette espèce se différencie des autres espèces du genre par un nombre différent de fentes dans le champ de fentes apicales aux extrémités opposées de la valve (i.e., 4 à l'extrémité possédant un rimoportula contre 5 à l'extrémité dépourvue de rimoportula), un rimoportula orienté apicalement et 3-4 bandes cingulaires non poreuses. Son habitat est différent de celui de toutes les espèces connues de *Synedropsis* Hasle, Medlin & Syvertsen car il est soit benthique soit épiphyte dans les tapis d'algues plutôt que planctonique ou associé à la glace de mer. La nouvelle espèce a été trouvée dans des eaux ayant une conductivité de 7,1 µS $^{cm-1}$ (salinité 3,3 psu) et une température de 33 °C. Les caractères morphologiques de la nouvelle espèce sont décrits à partir d'observations au microscope électronique à balayage et au microscope optique. Une comparaison de *S. abuflosensis* sp. nov. avec des espèces morphologiquement similaires est fournie.

MOTS CLÉS
diatomées araphides,
Fragilariaceae,
Irak,
rivière Shatt Al-Arab,
Synedropsis,
espèce nouvelle.

INTRODUCTION

Fragilarioid diatoms are a group of widely distributed araphid species inhabiting fresh, brackish and marine environments as pelagic and benthic forms, and are ecologically important in water quality monitoring (Morales 2001). Their fossil records have helped in reconstruction of past environmental conditions (Gasse *et al.* 1997; Salomoni *et al.* 2006). Historically, all fragillarioid species of needle-like valves were included in *Synedra* Ehrenberg or *Fragilaria* Lyngbye and were separated from each other merely by the shape of their colonies (Williams & Round 1986). Examination by scanning electron microscopy (SEM) revealed large variations in the morphological characters of species belonging to *Synedra sensu lato* and *Fragilaria sensu lato* which has led to the erection of many new genera. Freshwater and brackish water species formerly belonging to *Synedra* were transferred to *Fragilaria* or *Ulnaria* (Kützing) Compère, and those of brackish to marine preference were included in the newly erected genera *Catacombas* (Williams & Round), *Hyalosynedra* Williams & Round, *Tabularia* (Kützing) Williams & Round, *Ctenophora* (Grun.) Williams & Round, *Neosynedra* Williams & Round and *Synedropsis* Hasle, Medlin & Syvertsen. Separation of *Synedropsis* from *Synedra* was mainly based on the structure of the apical field which is formed of rows of poroid areolae (pore field) in *Synedra* and apical slits (slit field) in *Synedropsis*. Modern phylogenetic studies have emphasized the paraphyletic characters of *Synedropsis,* which appears to be most closely related to *Fragilaria*, *Grammatophora* (Lyngbye) Kützing, *Tabularia* (C. Agardh) Williams & Round and *Ulnaria* (Belando *et al.* 2018).

Synedropsis is a genus with a small number of described taxa. Since it was first documented 137 years ago as *Synedra hyperborea* Grunow (1884), only 11 taxonomically accepted species have been placed in the genus (Guiry & Guiry 2021). Another species has been reported, *Synedropsis creanii* Olney (Scherer *et al.* 2007), but its identity has not been verified. Until recently, this genus was comprised of only taxa inhabiting sea ice where six species were reported from Antarctica and only one from the Arctic (Hasle *et al.* 1994). Another Antarctic *Synedropsis* (*S. cheethamii* Onley) was reported by Olney *et al.* (2009) from the Oligocene to lower Miocene sediment, which is the first fossil record of the genus. The first subtropical brackish water species of *Synedropsis* (*S. roundii* Torgan, Menezes & Melo) was described in southeastern Brazil (Melo *et al.* 2003), followed by another subtropical species (*S. karsteteri* Prasad) in the Gulf of Mexico (Prasad & Livingston 2005). *Synedropsis roundii* was later reported from the Mediterranean Sea (Blanco *et al.* 2019), indicating a wide geographical distribution of the genus.

During our survey of benthic diatoms along the course of the Shatt Al-Arab River (200 km) in Southern Iraq we found a *Synedra*-like species at one location in the middle part of the river associated with a cyanobacterial mat occurring in patches on the sediment. Under the light microscope no structural detail could be resolved; however, SEM revealed an apical slit field, weakly developed striae bordering a wide sternum and a single rimoportula which strongly suggested a placement in *Synedropsis*. Its ultrastructural features do not match those of any known taxon, which led us to describe it as a new species.

MATERIAL AND METHODS

Study site

The Shatt Al-Arab River (30°50'07"N, 47°33'26"E) is the largest water basin in Southern Iraq and extends for 200 km southward to its mouth in the Arabian Gulf. The river is formed by the confluence of the Tigris and Euphrates Rivers which join at Qurna City, 60 km north of Basra City. The width ranges from 250 to 300 m in urban areas to *c.* 800 m at its delta, with a depth ranging between 6 and 15 m and a bed slope of *c.* 1.5 m.km^{-1} (Abdullah 2014). The river is strongly influenced by the Arabian Gulf tidal cycle. The tidal wedge may travel upstream for a distance exceeding 80 km, and is largely dependent on discharges

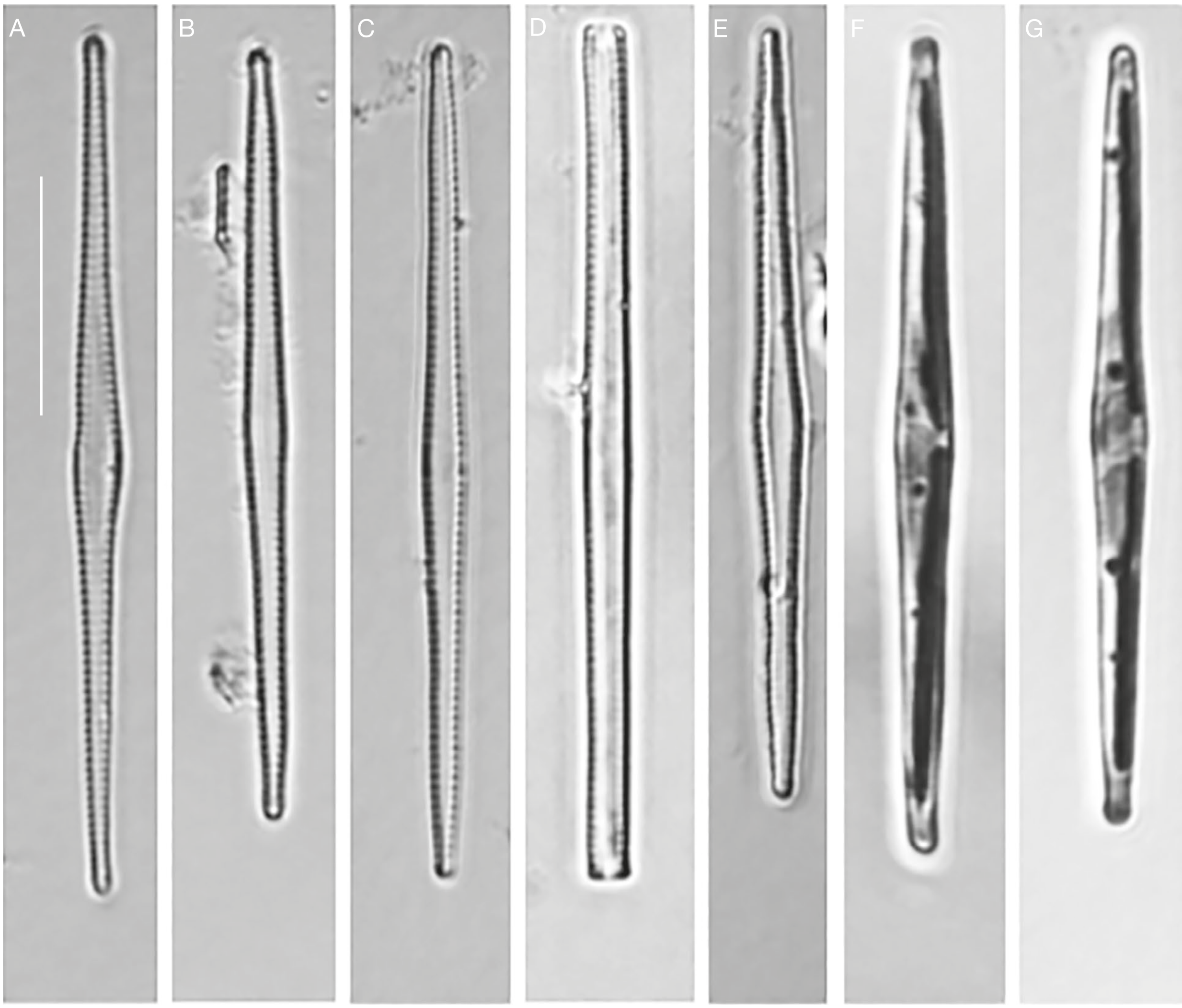

Fig. 1. — LM microphotographs of *Synedropsis abuflosensis* sp. nov. from Shatt Al-Arab River, Iraq. **A**-**C**, **E**, cleaned material showing variation in valve dimensions and outline; **A**, represents the holotype on slide deposited in the Botanischer Garten und Botanischer Museum (BGBM), Berlin, Germany under accession B 40 0045147; **D**, cell in girdle view; **F**, **G**, live cells in valve view showing the two elongated plastids occupying most of the valve. Scale bar: 10 µm.

from the Tigris and Euphrates Rivers. This intrusion of seawater exposes the river's biota to seawater during high tide and freshwater during low tide. Salinization of the river has become a problem due to the great reduction of water flow from the Tigris and Euphrates as a result of several dams constructed in Turkey and Syria. At present freshwater discharge to the Shatt Al-Arab river is as low as 60 m^3 s^{-1} which was 207 m^3 s^{-1} a few decades ago (Abdullah *et al.* 2016). The historical tributaries of the Shatt Al-Arab River (Karun and Karkha Rivers) which flow in the Iranian land were diverted, creating even more salinization problems. Currently, the Shatt Al-Arab River is characterized as weakly brackish (Lateef *et al.* 2020).

Sampling and preparations

Samples were collected during July-August 2020 from the eastern bank of the Shatt Al-Arab River at a region located 25 km south of Basra City opposite the Abu Flos area (30°27'08"N, 48°01'59"E).

Water temperature was measured using a mercury thermometer and salinity was determined with a portable conductivity meter (WTW Cond 3110, Germany). Diatoms were sampled by scraping the sediment surface from several locations at the site. Sediment in the region is formed of clay and silt with fragments of mollusk shells. All samples were kept in 15 ml plastic vials and preserved with 4 % formalin. Some vials were left without fixation for examination of live cells. Diatom material was washed with deionized water to remove salts and cleaned by boiling in 35 % hydrogen peroxide. Cleaned diatom frustules were left to dry on a cover slip at ambient temperatures and mounted in Naphrax. Diatoms were examined and photographed in LM with a Zeiss Axio imager microscope with differential interphase contrast (DIC) and a Canon PowerShot G6 digital camera (Marine Science Centre, University of Basra). For SEM observations the cleaned diatom aliquot was filtered through a 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 Nova NanoSEM 450 (Department of Physics, College of Science, Basra University) was operated at 8 kV and a working distance of 8 mm.

For terminology in describing valve structure we followed Ross *et al.* (1979) and Round *et al.* (1990). The term apical slit field was adopted by Hasle *et al.* (1994) to discriminate this structure from the widely used term apical pore field.

RESULTS

Class BACILLARIOPHYCEAE
Haeckel emend Medlin & Kaczmarska
Order FRAGILARIALES Silva
Family FRAGILARIACEAE Greville
Genus *Synedropsis* Hasle, Medlin & Syvertsen

Synedropsis abuflosensis
Al-Handal, Al-Shaheen, Al-Saedy & Wulff, sp. nov.
(Figs 1-3)

HOLOTYPE. — Permanent slide deposited in the Botanischer Garten und Botanischer Museum (BGBM), Berlin, Germany under accession number B 40 0045147. Collectors of specimens are Maitham A. Al-Shaheen and Rehab N. Al-Saedy. Fig. 1 illustrates the holotype. PhycoBank registration number: http://phycobank.org/102683

TYPE LOCALITY. — Abu Flos region, eastern side of the Shatt Al-Arab River, Southern Iraq, 30°27’08”N, 48°01’59”E.

ETYMOLOGY. — The epithet refers to the locality where the species was found.

ECOLOGY. — *S. abuflosensis* sp. nov. appeared in moderate numbers in the Abu Flos samples. Water conductivity at time of collection was 7.1 µS cm-1 (salinity = 3.3 psu) and water temperature 33 °C. The new species did not appear in any of the other samples collected from several places along the river course, both up and downstream. It was found associated with a cyanobacterial mat, mainly formed by Oscillatoria Vaucher & Gomont spp. Other common diatom taxa present in the samples were *Nitzschia obtusa* W. Smith, *Nitzschia palea* (Kützing) W. Smith, *Nitzschia elegantula* Grunow, *Fragilaria koensabbei* Al-Handal & Al-Shaheen and *F. iraqiensis* (Al-Handal & Kociolek) Rioual.

DESCRIPTION

Light microscope observations (LM) (Fig. 1): Cells solitary, rarely in pairs, with two elongated plastids lying on both sides of the central area (Fig. 1F, G). Frustules linear in girdle view (Fig. 1D). Valves linear to weakly linear-lanceolate with rounded apices, slightly inflated in the middle, 32-38 µm long and 1.5-3.5 µm wide (n = 50). Striae resolvable in LM, appearing as very small dots on valve margin.

Scanning electron microscope observations (SEM) (Figs 2; 3): Sternum wide in the middle, becoming narrower towards the apices. Central part of sternum reaches valve margins which are either devoid of striae or with delicate vestigial striae (Fig. 2A, B). In some specimens the hyaline central part of the sternum is asymmetric, being wider along one valve margin (Fig. 2A, D). Striae parallel, uniseriate, composed of rounded poroid areolae, one row is near the valve margin and the other on the mantle, 20-26 in 10 µm (Figs 2C, D, E; 3D). Each areola is occluded by a velum (Fig. 3E, black arrows). A rimoportula is present at only one apex of the valve with its internal opening oriented apically, positioned mostly opposite to the second row of areolae (Fig. 3B, arrow). The rimoportula opens externally as a small and irregular slit (Fig. 3A). The apical slit field is composed of parallel longitudinal slits, 4 at the valve pole with a rimoportula (Fig. 3B) and 5 at the opposite pole (Fig. 3C). The cingulum is composed of 3-4 delicate, open and non-porous copulae (Fig. 3D).

DISCUSSION

In LM the valve outline of *Synedropsis abuflosensis* sp. nov. appears similar to that of *S. roundii* which was first described from a tropical coastal lagoon in southeastern Brazil (Melo *et al.* 2003). The valves of *S. roundii* are more slender, narrower, and terminate with subcapitate apices in comparison to the mainly rounded apices of *S. abuflosensis* sp. nov. The widest central portion of *S roundii* valves does not exceed 1.8 µm while that of *S. abuflosensis* sp. nov. may reach 3.5 µm. The main characters that separate these two superficially similar species are the number of plastids, the orientation of the rimoportulae and the number of slits in the apical pore field (Table 1). *Synedropsis abuflosensis* sp. nov. possesses two elongated plastids, an apically oriented rimoportula and 4-5 apical slits compared to a single plastid, transapically oriented rimoportulae and 3 apical slits in *S. roundii*. The ecology of the two species is different: *S. roundii* is a bloom-forming planktonic species whereas *S. abuflosensis* sp. nov. is a benthic taxon.

Another warm water planktonic and bloom-forming species that is similar to *S. abuflosensis* sp. nov. is *S. karsteteri* Prasad in Prasad & Livingston (2005). The latter taxon was described from Perdido Bay, northeastern Gulf of Mexico. Both species possess two plastids; however, valves of S. *karsteteri* are shorter with denser striae (24-40 in 10 µm compared to 20-26 in our new taxon). The number of slits in the apical field is 2-3 in *S. karsteteri* while it is 4-5 in *S. abuflosensis* sp. nov. The orientation of the internal opening of the rimoprortula is also different; it is transapical to rarely oblique in the former and apical in the latter species.

The valve outline of *S. abuflosensis* sp. nov. also resembles that of the polar species *S. fragilis* and *S. hyperborea* but the valve ultrastructure is different. The striae of the two polar species are composed of transapical rows of multiple areolae on the valve face that define a narrow sternum, whereas in *S. abuflosensis* sp. nov. there is only a single areola on the valve face. The number of slits in the slit field is greater in *S. fragilis* and *S. hyperborea* (Table 1), and the orientation of the rimoportula is either transapical or oblique rather than apical as in our new species. In all documented species of *Synedropsis* only the Antarctic *S. hyperboreoides* possesses apically oriented rimoportulae (Hasle *et al.* 1994: fig. 49). Table 1 presents differences between some of the known *Synedropsis* taxa and the newly found species.

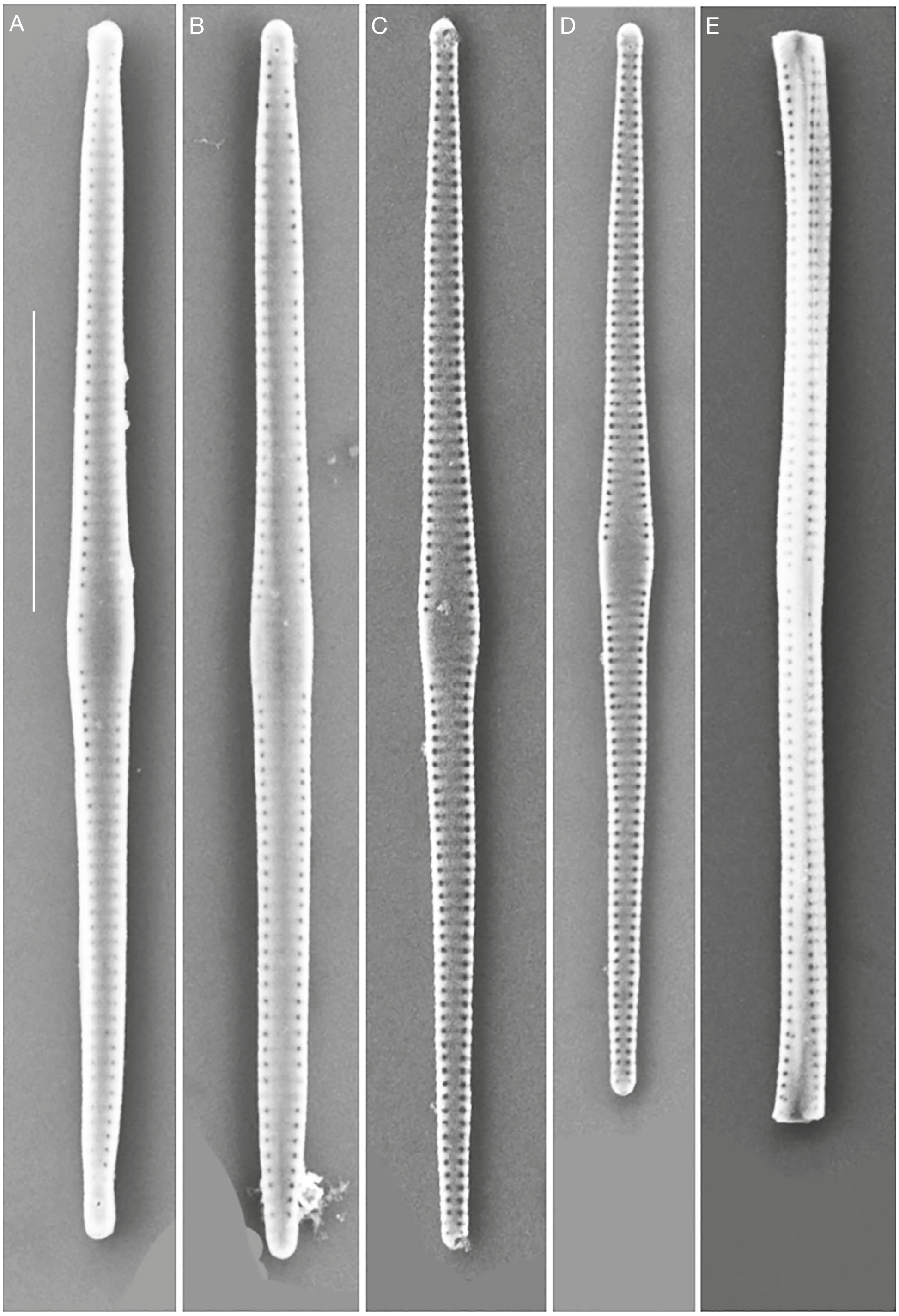

Fig. 2. — SEM microphotographs of *Synedropsis abuflosensis* sp. nov. from Shatt Al-Arab River, Iraq. **A**, **B**, external view of whole valve showing marginal uniseriate striae; **C**, **D**, internal view of the whole valve; **E**, cell in girdle view exhibiting curvature of the frustule. Scale bar: 10 µm.

In *S. abuflosensis* sp. nov., the number of slits in the apical slit field differs at the valve poles (4 at the pole which bears the rimoportula and 5 at the opposite pole) (Fig. 3B, C). Hasle *et al.* (1994: 261) reported that in *S. lata* the valve pole bearing a rimoportula has 4-7 slits whereas the opposite pole has 5-8 slits. However, these authors did not provide any data concerning the number of slits at opposite ends of the same valve so it cannot be determined if the end with the rimoportula had fewer or more slits than the opposite end. In *S. abuflosensis* sp. nov. we did not observe any variation in slit numbers.

Hasle & Syvertsen (1996) placed *Synedropsis* in the araphid family Fragilariaceae. Since then the work of Lange-Bertalot (1980); Williams & Round (1986, 1987); Krammer &

TABLE 1. — Morphometric features of *Synedropsis abuflosensis* sp. nov. compared to related taxa. Abbreviation: **nd**, not detected.

Feature		***Synedropsis abuflosensis*** sp. nov.	***S. roundii*** Torgan, Menezes & Melo	***S. karsteteri*** Prasad	***S. fragilis*** Hasle, Medlin & Syvertsen	***S. hyperborea*** Hasle, Medlin & Syvertsen	***S. recta*** Hasle, Medlin & Syvertsen	***S. laevis*** Hasle, Medlin & Syvertsen
Valve	Length (µm)	32-38	29-44	15-28	26-58	13-96	17-48	14-62
	Width (µm)	1.5-3.5	1.4-1.8	1.4-2.5	3-4	2.5-4	3.5-5	4
	Outline	linear lanceolate	linear lanceolate	linear, needle shaped	lanceolate	linear, variable with size	linear	lanceolate
	Apices	rounded	linear-attenuate slightly capitate	rounded	obtuse	rounded	rostrate, subcapitate	rounded
	Sternum	wide	wide	wide	highly variable	linear, narrow	wide	wide
	Striae/10 µm	20-26	20-24	25-40	21-24	25-27	11-14	12-14
	Areolae/10 µm	28-30	22-23	30-40	50-60	50-60	nd	40-80
	Rimoportulae	apically oriented	transapically oriented	transapically oriented	transapically oriented	transapically oriented	transapically oriented	oblique, excentrical
	Apical porefield slits	4-5	3	2-3	6-7	4-6	5-8	4-8
	Plastids	2 plate-like	1 plate-like	2 thin, elongated	2 plate-like	nd	nd	nd
Frustules	copulae	3-4	several	6	nd	6	4	nd
Habitat and life mode		subtropical, brackish water, benthic, epiphytic	tropical, brackish water, planktonic	subtemperate, brackish water, planktonic	Antarctic, marine, benthic	Arctic, marine, sea ice	Antarctic, marine, sea ice	Antarctic, marine, sea ice
Reference		Present study	Melo *et al*. (2003)	Prasad & Livingston (2005)	Hasle *et al*. (1994)	Hasle *et al*. (1994)	Hasle *et al*. (1994)	Hasle *et al*. (1994)

Lange-Bertalot (1991, 2000) and Lange-Bertalot & Compère (2001) has brought attention to the polymorphism that characterizes diatom species comprising the Fragilariaceae. Differentiating characters used to separate the genera include: 1) Structure, shape and position of the apical field which varies considerably from well-developed to very simple to even its presence at only one valve apex such as in *Punctastriata* Williams & Round; 2) Number, position and orientation of the rimoportulae which are quite variable and in genera such as *Staurosirella* Williams & Round, *Staurosira* Ehrenberg, *Pseudostaurosira* Williams & Round, *Punctastriata*, *Martyana* Round, *Opephora* Petit and *Trachysphenia* Petit rimoportulae are lacking. Rimoprtulae are not only present in the Fragilariaceae but occur in centric diatoms and biraphid species of the Eunotiales; 3) Striae patterns and structure of the areolae, which vary from simple poroids to structurally complex structures; and 4) Ecology and life forms from single cells to colony formation which were historically the criteria for separating *Fragilaria* from *Synedra*. In her treatment of the Fragilariaceae Cox (2015) proposed several characters that hold the genera comprising the Fragilariaceae together. These include elongate cells often forming filaments held together by marginal spines, apical pore fields and rimoportulae usually present. Some of these features, however, do not appear to be present in certain genera where frustules are devoid of rimoportulae and spines.

The separation of *Synedropsis* from *Synedra* (Hasle *et al*. 1994) was based on the following characters of the former genus: valves possess slit fields, rimoportula at only one valve apex and striae rows not separated by well-developed virgae in the valve interior. This latter feature excluded *Falcula* Voigt, which also possesses slit fields and a single rimoportula, from being included in *Synedropsis* because its valves are furnished with well developed virgae that separate the areolae internally. Both Hasle *et al*. (1994) and Prasad & Livingston (2005) speculated that species belonging to *Synedropsis* possess distinguishing features that place them apart from other members of the Fragilariaceae and hence should be assigned to a different family.

Our new species appears to be newly introduced to the Shatt Al-Arab River. It was not found in the previous extensive survey of diatoms made by Al-Handal & Al-Shaheen (2019) who gathered monthly diatom samples during 2013-2014. The large decrease of freshwater discharge from Tigiris and Euphrates Rivers in the past few decades caused a significant elevation of salinity (Al-Mahmood *et al*. 2008). Consequently, seawater from the Arabian Gulf penetrates further upstream during high tide causing large temporal fluctuations in salinity (Al-Handal & Al-Shaheen 2019). This may have allowed the introduction of brackish water species not previously known in the river such as *S. abuflosensis* sp. nov. In comparison to the ecology of other species of *Synedropsis* which vary from sea ice dwellers (Hasle *et al*. 1994) to bloom-forming planktonic forms (Melo *et al*. 2003; Prasad & Livingston 2005), the new species occupies a new ecological niche being associated with cyanobacterial mats on a clay and silty sediment.

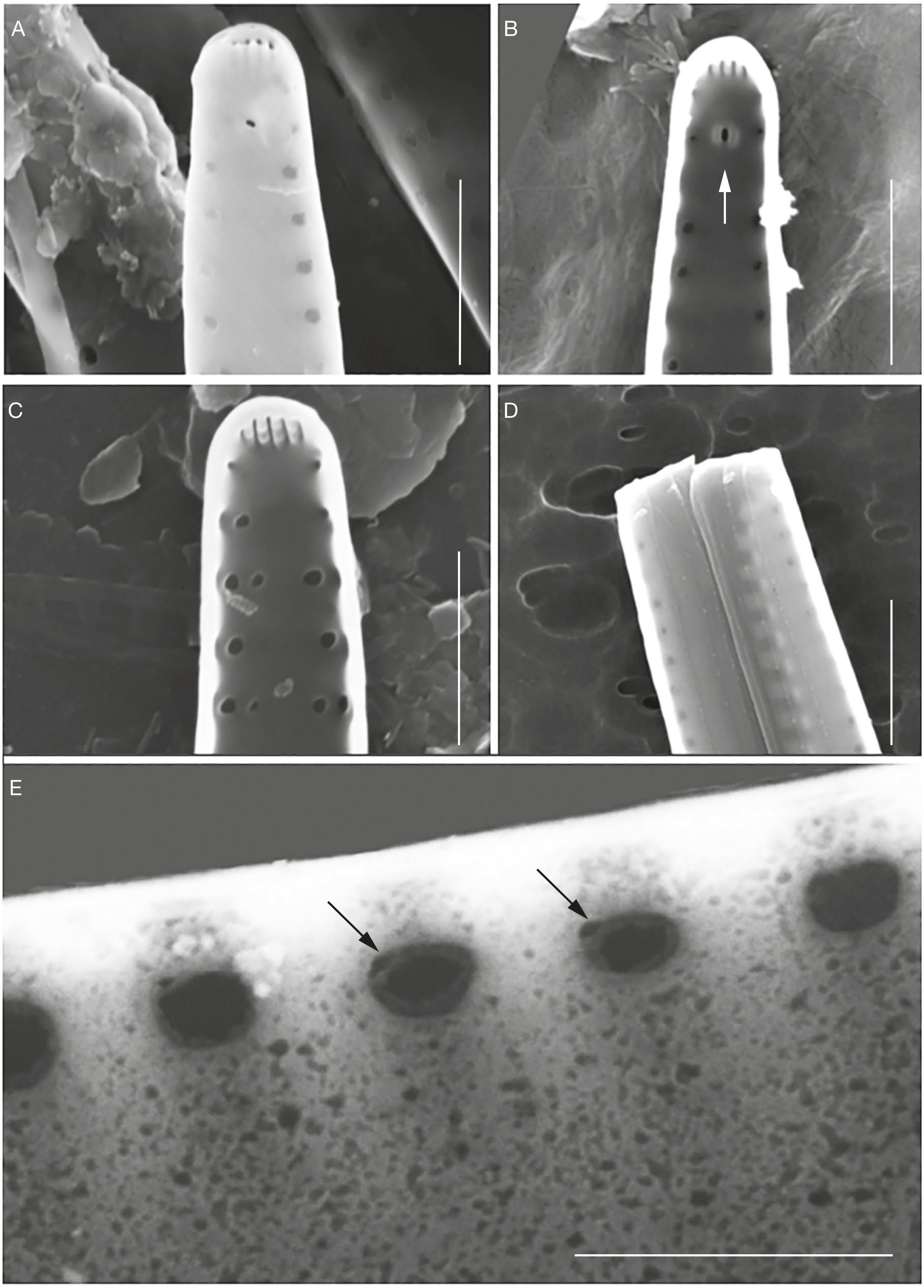

Fig. 3. — SEM microphotographs of *Synedropsis abuflosensis* sp. nov. from Shatt Al-Arab River, Iraq. **A**, external apical part of the valve showing the very small external opening of the rimoportula; **B**, internal apical part of the valve showing the apical orientation of the rimoportula and four apical slits in the slit field (white arrow); **C**, valve apex without rimoportula and five apical slits; **D**, girdle view of the frustule pole showing row of areolae on valve mantle and three cingular copulae; **E**, enlargement of areolae showing remains of vela which were damaged during the cleaning process. Scale bars: A-D, 2 µm; E, 1 µm.

TABLE 2. — World distribution and up to date records of known *Synedropsis* Hasle, Medlin & Syvertsen species.

Species	Distribution
Synedropsis abuflosensis Al-Handal, Al-Shaheen, Al-Saedy & Wulff, sp. nov.	Benthic and epiphytic brackish water, subtropical species in Shatt Al-Arab River, Southern Iraq (30°27'08"N, 48°01'59"E), associated with the cyanobacteria *Oscillatoria* sp. (present study).
Synedroposis roundii Torgan, Menezes & Melo	Planktonic brackish water species, Imboassica Lagoon. (22°24"S, 41°42"W) Macaé, Rio de Janeiro, Brazil and Albufera of Valencia (39°20"N, 0°21"W), Mediterranean coast, Spain (Melo *et al*. 2003, Blanco *et al*. 2019).
Synedropsis karsteteri Prasad	Planktonic brackish water species, tropical to subtropical, Perdido Bay, Florida, northeastern Gulf of Mexico (30°27'23"N, 87°22'73"W) (Prasad & Livingston 2005).
Synedropsis fragilis (Manguin) Hasle, Medlin & Syvertsen	Antarctic marine sea ice species, rocky sea bottom, Kita-no-ura Cove, East Antarctica (Hasle *et al*. 1994).
Synedropsis hyperborea (Grunow) Hasle, Medlin & Syvertsen	Benthic and epiphytic circumpolar marine species associated with sea ice and *Melosira arctica* in the Arctic, east cost of Greenland, Frobisher Bay, Denmark Strait, also the Baltic Sea (Hasle & Syvertsen 1990, Hasle *et al*. 1994).
Synedropsis hyperboreoides Hasle, Medlin & Syvertsen	Antarctic marine sea ice species. Found in Queen Maud Land, Weddell Sea, East Antarctica (Hasle *et al*. 1994).
Synedropsis recta Hasle, Medlin & Syvertsen	Marine sea ice and benthic circumpolar species, Weddell Sea, Terre Adélie, Cape Armitage, McMurdo Sound, Ongul Islands, East Antarctica, also from the South Atlantic (Hoshiai *et al*. 1987, Hasle *et al*. 1994).
Synedropsis laevis (Heiden) Hasle, Medlin & Syvertsen	Antarctic circumpolar sea ice species, Ongul Island, Cap Margerie, Ross Sea (Hasle *et al*. 1994).
Synedropsis lata Hasle, Medlin & Syvertsen	Antarctic sea ice species. No information about its distribution in Antarctica.
Synedropsis cheethamii Olney	Fossil marine Antarctic species, Cape Roberts (77°00'21"S, 163°43'8"E), Victoria Land Basin, Ross Sea, Antarctica.
Synedropsis varipunctata (John) John & Williams	Freshwater Antarctic species. No information about its distribution in Antarctica.
Synedropsis waernii Snoeijs	Epiphytic brackish water species, Swedish coast, the Baltic Sea, Sea (Snoeijs & Kuylenstierna 1991).

The world wide distribution and ecological preferences of *Synedropsis* species are not yet well known and at present seems to be limited to the geographical locations from which the species were first described. One exception is *S. roundii* which is the first taxon found outside its type locality. Table 2 presents the currently known distribution of *Synedropsis* species.

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