Seminavis aegyptiaca sp. nov., a new amphoroid diatom species from estuary epilithon of the River–Nile Damietta Branch, Egypt

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Abstract: During a recent floristic–taxonomic study on the algal flora, including diatoms, from the estuary of the Damietta Branch of the Nile in Egypt, an interesting epilithic diatom species belonging to the genus Seminavis (Naviculaceae) was collected and investigated using both light and scanning electron microscopy. This new diatom species shares morphologically some taxonomic diagnostic features with other related taxa such as S. insignis, S. robusta, and S. ventricosa. However, it still differs by having ventral central striae that are shorter and more or less straight in the middle of the smaller frustules to be clearly radiate in the larger ones and then become geniculate and only radiate near the poles, the central raphe endings are externally more distantly spaced than in the similar species, the elongate central nodule is internally less prominent, and the areola density is much denser. Therefore, we here describe it as Seminavis aegyptiaca sp. nov. Hydrochemical analyses revealed that S. aegyptiaca commonly inhabits typical marine, with a weak tendency towards brackish water, habitats. It was found to be tolerant to meso–eutrophic, nutrient–enriched conditions, based on the data available on seasonal concentrations of N and P compounds. These findings not only contribute to the inventory of Egyptian diatoms, but also increase our understanding of the autecology and distribution of this relatively poorly–known diatom genus.

Key words: benthic diatoms, Egypt, morphotaxonomy, new species, Seminavis, the Nile River

INTRODUCTION

Seminavis D.G. Mann was first described by MANN in ROUND et al. (1990), where he separated it from its most closely related genus Amphora Kützing based on the following key taxonomic features: (1) two plate–like, girdle–appressed plastids of unequal size; (2) uniseriate striae with apically–elongate, slit–like areolae; (3) several distinct ultrastructural characters of the raphe sternum and girdle bands. The aforementioned diagnostic characters make Seminavis a member of the family Naviculaceae sensu stricto (ROUND et al. 1990; COX 1999), despite the strong dorsiventrality that is the main feature shared with the genus Amphora. Moreover, a cladistic study by COX & REID (2004), mainly based on protoplast and frustule characteristics on the generic relationships within the suborder Naviculineae, placed the genus Seminavis within the Navicula subclade. The valve symmetry shift in Seminavis is thus perhaps the most extreme within the family Naviculaceae, leading not only to the development of amphoroid shapes but also involving a change in the organization of cell division and valve ontogeny (ROUND et al. 1990).

During the last three decades, many taxonomic studies were carried out on the genus Seminavis, resulting in the description or transfer of several species (e.g., DANIELIDIS & MANN 2002, 2003; DANIELIDIS et al. 2006; GARCÍA 2007; WACHNICKA & Gaiser 2007; TALGATTI et al. 2017). In parallel, certain taxa in closely allied genera, e.g. Cymbella C.A. Agardh, underwent in–depth taxonomic revision. For instance, TALGATTI et al. (2014) studied the type material of Cymbella (Encyonema) grossestratiata var. recta Frenguelli from Argentina and
fresh specimens collected from southern Brazil, and proposed the newly described taxon *Seminavis norae* (Metzeltin, Lange–Bertalot et Garcia–Rodriguez) Talgatti et Torgan because it shared the key characteristics of the genus *Seminavis*. Twenty–three species have been described in the genus *Seminavis* so far, in particular thanks to the significant taxonomic work over the last years. From the molecular and phylogenetic standpoints, little is known about the evolutionary position of these taxa. However, Brüder & Medlin (2008) suggested that the genus *Seminavis* is monophyletic in origin, and had arisen from the *Navicula* sensu stricto group. Ecologically, *Seminavis* mainly inhabits brackish and marine habitats (Guiry & Guiry 2019).

Considerable morphotaxonomic studies carried out on the diatom flora of different Egyptian inland–water habitats, including the main basin and branches of the Nile River (e.g., Foged 1980; Saaban 1994; Hämed 2008; Shaaban et al. 2012; El–Baba & Iskarak 2015; Abdel–Satar et al. 2017; El–Sheikh et al. 2018), did not use scanning electron microscopy (SEM), thus unintentionally neglecting ultrastructural details which play a crucial role in accurate species delimitation. As a consequence, very little information is available for Egypt on the diversity and autecology of diatoms belonging to *Seminavis* and other morphologically similar amorphoid taxa (e.g., *Seminavis strigosa* Hustedt) Danieledis et Economou–Amilli as cited in Danieledis & Mann (2003), recorded under the name *Amphora strigosa* Hustedt in the desert springs of Ayun Musa and Wadi Islet in the Sinai Peninsula, and *Seminavis robusta* D.B. Danielidis et D.G. Mann – originally *Amphora angusta* var. *ventricosa* (W. Gregory) Cleve – that was recently reported by Saleh (2009) from the desert inland saline spring ‘Ain El–Araes’ in the Siwa Oasis (Western Desert of Egypt) during her recent monographic study on the order Naviculales in Egypt.

In this paper, using both light and scanning electron microscopy, we describe a new species within the genus *Seminavis* collected from the epilithon of the estuary of the Damietta Branch (the Nile River, Egypt), during our recent in–depth floristic–taxonomic and bioassessment studies on the algal communities in this pivotal but highly–impacted habitat.

**Materials and Methods**

**Study site.** The Damietta Branch is one of the two main branches of the Nile River, splitting North of Cairo and extending to the East over a distance exceeding 240 km until reaching the Mediterranean Sea. It has an average width of about 280 m and a depth ranging between 12 and 20 m. It is dammed ca. 20 km inland of the river mouth by an artificial dam known as Faraskur Dam Barrage (Kheir 1998), forming the estuary (Fig. 1). Along its main basin, the Damietta Branch serves as an important water resource for agricultural, domestic, and industrial activities (Negm et al. 2017). However, this vital water artery and its estuary are negatively influenced by fish farming, in addition to wastewater and agricultural discharges (ElBereay et al. 2017). Sampling sites along the estuary were arranged towards the Mediterranean Sea as follows: site 1 (31°24'54.8"N, 31°48'17"E), site 2 (31°25'29.5"N, 31°48'46.6"E), site 3 (31°26'41.2"N, 31°47'39.2"E), site 4 (31°27'42"N, 31°48'7.8"E), site 5 (31°28'31.6"N, 31°49'29.7"E), and site 6 (31°31'35.6"N, 31°50'38.3"E).

**Diatom sampling, preparation, and identification.** Thirty diatom samples (epilithon), on which this study is based, were seasonally collected starting from April 28th 2015 (spring season of 2015) to April 27th 2016 (spring of 2016), from six different localities along the estuary of the River–Nile Damietta branch during our recent in–depth floristic–taxonomic study, following the European standard methods for sampling diatoms in running waters (EN 15708 2009). Samples were treated with hydrogen peroxide (33%) and hydrochloric acid (37%), to remove organic matter. After several rinses in distilled water, the diatoms were mounted with Naphrax®, a synthetic mounting medium with a high refractive index of 1.74. Light microscope (LM) observations were made using a Zeiss Axioskop 2 microscope (Zeiss, Jena, Germany) equipped with phase–contrast and with an AxioCam digital camera. Scanning electron microscopy (SEM) observations were made at the MUSE – Museo delle Scienze, Trento, Italy using a LEO XVp scanning electron microscope (Carl Zeiss SMT Ltd., Cambridge, UK) at high vacuum on gold–coated prepared material. Measurements on at least 30 different specimens representative of the size–diminution series were made to obtain ranges and averages of the morphological and ultrastructural features. Diatom micrograph images were arranged in plates with Adobe Photoshop CS6. Permanent mounts (including the holotype shown in bold in the list below) were deposited at both Algae Lab, Botany and Microbiology Department, Faculty of Science, Al–Azhar University, Cairo, Egypt, and the Phycology Unit (No. 341), Botany Department, Faculty of Science, Ain Shams University; Thiers 2018), Cairo, Egypt

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**Fig.1.** Location of the sites where *Seminavis aegyptiaca* sp. nov. was sampled.
Table 1. Average (minimum – maximum) values for selected chemical and physical variables measured at sites where Seminavis aegyptiaca sp. nov. was collected.

| Parameters | Average (min – max) |
|------------|---------------------|
| Temperature (°C) | 23.5 (15.9 – 34.4) |
| pH | 7.89 (6.19 – 8.46) |
| Total alkalinity (mg.l⁻¹) | 224.8 (145 – 385) |
| Conductivity (mS.cm⁻¹) | 42.79 (27.7 – 58) |
| T.D.S. (g.l⁻¹) | 28.6 (17.7 – 40.6) |
| Na⁺ (g.l⁻¹) | 9.56 (5.2 – 17) |
| K⁺ (mg.l⁻¹) | 110.53 (60 – 360) |
| Ca²⁺ (mg.l⁻¹) | 490.46 (240.6 – 761) |
| Mg²⁺ (mg.l⁻¹) | 295.41 (111 – 1336.5) |
| Cl⁻ (g.l⁻¹) | 13.83 (1.76 – 19.72) |
| SO₄²⁻ (mg.l⁻¹) | 1601.5 (975 – 2404) |
| HCO₃⁻ (mg.l⁻¹) | 213.18 (102 – 385) |
| NO₃⁻ (mg.l⁻¹) | 12.63 (4.8 – 43.2) |
| NO₂⁻ (µg.l⁻¹) | 124 (7 – 655) |
| NOₓ (µg.l⁻¹) | 162 (60 – 300) |
| NH₄⁺ (µg.l⁻¹) | 5361 (34 – 19720) |
| SRP (µg.l⁻¹) | 204 (30 – 450) |
| SiO₂ (mg.l⁻¹) | 1.26 (0.2 – 3.89) |
| Cu (µg.l⁻¹) | 27.8 (1 – 244) |
| Zn (µg.l⁻¹) | 23.9 (17 – 284) |
| Al (µg.l⁻¹) | 10.1 (6 – 103) |
| Ba (µg.l⁻¹) | 10.6 (5 – 30) |
| Cr (µg.l⁻¹) | 8.3 (3 – 44) |
| Pb (µg.l⁻¹) | 4.6 (3 – 51) |

Hydrochemical characterization. Water sampling for the hydrochemical analyses was conducted using polyethylene bottles which had been previously cleaned with ultrapure water and superpure nitric acid (1%). Water temperature (°C), pH, electrical conductivity (EC, mS.cm⁻¹), and total dissolved solids (TDS, g.l⁻¹) were measured in situ using the calibrated portable Temp/pH/EC/T.D.S. HANNA HI 991301 meter. Total alkalinity, major ions and nutrients were analyzed following standard procedures and methods (CLESCERI et al. 2000). Concentrations of major ions, including sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺) and magnesium (Mg²⁺), were measured using ionic chromatography (ICS 1500 Dionex Corp.). Bicarbonate (HCO₃⁻), carbonate (CO₃²⁻), chloride (Cl⁻) and sulphate (SO₄²⁻) concentrations were determined according to CHAPMAN & PRATT (1978). Nutrient concentrations, namely nitrite (NO₂⁻), nitrate (NO₃⁻), ammonium (NH₄⁺) and soluble reactive phosphorus (SRP), were analysed by molecular absorption spectrometry and silica (as SiO₂) was estimated by the molybdosilicate method (CLESCERI et al. 2000).

Results

Seminavis aegyptiaca A.A. Saber, El–Belely, El–Refaey, El–Gamal, Blanco et Cantonati sp. nov. (Figs 2–10, 11–17)

Light microscopy (Figs 2–10): Valves lanceolate to rhombic–lanceolate, with more or less obtusely rounded ends. Valve length (27.5) 30–75 µm, valve width 7.5–10.0 µm. Dorsal margin distinctly convex. Ventral margin straight, particularly in small frustules (Figs 2–3), to slightly convex in the larger specimens (Figs 4–9). Length–to–breadth ratio ca. 5.0–7.5. The axial area is almost two times wider on the dorsal side than on the ventral one, with a central roundish expansion on the ventral side, particularly in the larger valves. The axial area is separated from the ventral side and the gibbous dorsal part by grooves, which in LM have the appearance of dark lines running along the raphe. The raphe is straight, running parallel to the ventral margin, and ventrally displaced with respect to the midline of the valve. The central raphe endings are slightly expanded and deflected ventrally and relatively close to each other (Figs 4, 6), while the terminal raphe fissures are hooked dorsally. The dorsal striae are more or less radiate in the central part of the valve, (16) 17–19 in 10 µm, and becoming denser, 19–21 in 10 µm, near the apices. The ventral striae are shorter and more or less straight in the middle of the smaller specimens to become clearly radiate in the larger ones, then become geniculate and only radiate near the poles, (14) 15–17 in 10 µm at the valve center, much denser and relatively parallel at the poles, 19–21 in 10 µm near the apices. The cingulum is simple and unornamented (Fig. 10).

Scanning electron microscopy (Figs 11–14 external views, Figs 15–17 internal views): The valve face is curving into a deep dorsal mantle whilst the ventral mantle is reduced. Externally, the stria areolae in general have the typical Seminavis morphology with uniseriate, apically–elongate, slit–like openings (Figs 11–13). Areola density (n = 25) is 55–60 in 10 µm. The ridge on which the raphe runs is prominent, and slightly dorsally–bent near the apices (Figs 11–12). The central raphe endings are slightly expanded and deflected to the ventral side, and close to each other (Fig. 13). The valvocopula (Figs 14–15) is composed of three plain and unornamented bands, first being much wider, the second reduced to a small ligulate segment occupying the gaps left at poles by the ends of band I (Fig. 15), and the third one being a narrow abvalvar element (Fig. 14). Internally, the valve structure in general resembles that of all other Seminavis species. The internal areola openings are also slit–like
Therefore, it can be concluded that this diatom species wastes, in addition to being influenced by fish farming. Some of the localities where the estuary (Check Table 1 for more details). Noticeably, human impacts (including agriculture) highly affecting concentrations. Cu, Zn, Al, Ba, Cr, and Pb were the heavy eutrophic habitat based on N (seasonal average values of Ca, Na, Mg, and K were 124, 162, and 5361 mg l⁻¹, respectively) and P (SRP up to 450 µg l⁻¹) concentrations. Cu, Zn, Al, Ba, Cr, and Pb were the heavy elements having high concentrations due to different human impacts (including agriculture) highly affecting the estuary (Check Table 1 for more details). Noticeably, some of the localities where S. aegyptiaca was found were contaminated by motor oils, gasoline, and solid wastes, in addition to being influenced by fish farming. Therefore, it can be concluded that this diatom species is tolerant to different types of pollution.

The diatom species most common (> 20%) in the slides in which S. aegyptiaca were recorded: Cyclotella stylum Brightwell, Achnanthes brevipes var. intermedia (Kützing) Cleve, Fallacia sp. Stickle et D.G. Mann, Halamaphora coffeaeformis (Agardh) Z. Levkov, Navicula tri punctata (O.F. Müller) Bory, Nitzschia clausii Hantzsch, Nitzschia frustulum (Kützing) Grunow, Nitzschia gracilis Hantzsch, Nitzschia kurzkeana Rabenhorst, Opephora sp. Petit, Psammodesis nitidus (W. Gregory) Round et D.G. Mann, and Tabularia fasciculata (C. Agardh) D.M. Williams et Round.

**Discussion**

In this study, Seminavis aegyptiaca sp. nov. is assigned to the genus Seminavis by virtue of possessing all key diagnostic features of this genus, particularly the valve morphology and details of the axial area, raphe, and areola construction (Round et al. 1990; Danielidis & Mann 2002, 2003). The species most similar to ours are Seminavis insignis Álvarez–Blanco et S. Blanco, S. robusta, and S. ventricosa (W. Gregory) M. García–Baptista. Seminavis aegyptiaca can be distinguished from the aforementioned taxa, and others in this poorly investigated genus, by having (1) a much higher areola density; (2) central ventral striae being shorter and more or less straight in the middle of the smaller frustules to be clearly radiate in the larger ones, and then becoming geniculate and only radiate near the poles; (3) internally, the small, elongate central nodule is clearly less prominent; (4) the central raphe endings are externally more distantly spaced than in the mentioned species (Figs 2–17); Table 2). Additionally, all these morphologically similar taxa can be separated based on other taxonomic features. As regards S. insignis, (1) its valve width is narrower than S. aegyptiaca (5.0–7.5 µm vs. 7.5–10 µm, respectively), (2) the central raphe endings are deflected dorsally whilst in S. aegyptiaca they are slightly expanded, more distant, and deflected to the ventral side, (3) the dorsal striae are parallel in the central part, 20–26 in 10 µm, clearly radiate, and much denser at the poles, 24–28 in 10 µm (while S. aegyptiaca has radiate dorsal striae in the valve centre, 17–19 in 10 µm, and striae are becoming much denser, 19–21 in 10 µm, near the apices), (4) the ventral striae are much denser (19–23 in 10 µm at the valve centre and 22–26 in 10 µm at the poles vs. 15–17 in 10 µm at the valve middle and 19–21 in 10 µm near the apices in S. aegyptiaca), and (5) the areola density is much lower (48–52 in 10 µm).

Another very similar species is Seminavis robusta. However, it differs in the arrangement of the ventral striae, i.e. S. robusta has distinctly radiate ventral striae in the valve centre whilst in S. aegyptiaca the ventral striae are more or less straight in the centre of smaller frustules to be clearly radiate in larger ones. Additionally,
the raphe ridge is internally bearing the central slits on a longitudinal thickening. This key taxonomic feature is absent in *S. aegyptiaca*, which has a distinctly elongate and less prominent central nodule. Finally, the areola density in *S. robusta* (as it results from our own measurement made on the SEM image Fig. 50 in the original paper published by Danielidis & Mann 2002) is much lower than that found in *S. aegyptiaca* (46–50 in 10 µm vs. 55–60 in 10 µm).

The last morphologically allied species is *Seminavis ventricosa* which is distinguished from *S. aegyptiaca* by having (1) larger frustules (51.5–101 µm); (2) evidently drawn-out valve apices; (3) central raphe endings deflected ventrally but with central pores pointing towards opposite directions; (4) central part of the raphe entering a narrow ‘gorge’ before opening out again near the raphe endings; (5) much lower dorsal and ventral stria densities (*S. ventricosa* has 10–12.8 in 10 µm for dorsal striae and 10–12.1 in 10 µm for ventral striae); the central dorsal stria that is usually missing—at least on the adaxial side—or reduced, not reaching the axial area; (6) the dorsal side of the axial area that is wider internally than externally and that combines with the transapical costae to form small chambers at the...
Figs 11–17. SEM images of *Seminavis aegyptiaca* sp. nov.: (11) external view of the whole valve; (12) external view of the pole showing the dorsally-hooked apical raphe fissure and the simple row of apical pores (arrowhead); (13) close-up view on the valve mid-section showing the ventrally-deflected central raphe endings, two grooves (arrowheads) on opposite sides of the axial raphe sternum, and wide dorsal mantle (arrow); (14–15) details of plain and unornamented valvocopula with a narrow abvalvar segmental element (arrowhead; Fig. 14), much wider central girdle band (arrowhead; Fig. 15), and the small ligulate segment occupying the gaps left at poles (arrow; Fig. 15). Note the rib on which the raphe runs and slightly dorsally-bent near the apices (double arrowheads); (16) internal central portion of the valve showing central raphe endings, the less prominent central nodule, striaation pattern and chambering of ventral and dorsal striae. Note also the raphe rib (arrowhead) and the thickened rib-like extension of the ventral lamina (arrow); (17) close-up view on the internal pole region of the valve showing the ventrally bent, terminal helictoglossa (arrowhead) and the apical pit-like depression beyond the helictoglossa containing simple pores that open to the interior (arrow). Scale bars 5 μm (11, 14–16), 2 μm (12, 13, 17).
Table 2. Morphometric data of *Seminavis aegyptiaca* sp. nov. compared with other morphologically related species.

| Features / Species       | *Seminavis aegyptiaca* sp. nov. | *Seminavis insignis* | *Seminavis robusta* | *Seminavis ventricosa* |
|--------------------------|----------------------------------|----------------------|---------------------|------------------------|
| Reference                | this study                       | Álvarez–Blanco & S. Blanco (2014) | Danielidis & Mann (2002) | (W. Gregory) M. García–Baptista (1993) |
| Valve morphology         | lanceolate to rhombic–lanceolate with more or less obtusely rounded ends | semi–lanceolate with obtusely rounded apices | lanceolate to rhombic–lanceolate with obtusely rounded ends | lanceolate with evidently drawn-out apices |
| Valve length (µm)        | (27.5–) 30–75                    | 24.0–57.7            | 34–68               | 51.5–101               |
| Valve width (µm)         | 7.5–10                           | 5.0–7.5              | 6.5–9.5             | 6.0–10                 |
| L/W ratio                | ca. 5–7.5                        | –                    | –                   | –                      |
| Raphe                    | straight, proximal endings external–more distant, deflected ventrally, and hooked dorsally at the apices. Internally, central raphe endings within a small and elongate nodule | straight, central ends deflected dorsally. Internally, central endings in a small elongate nodule | straight, the proximal endings deflected ventrally and apically hooked dorsally. Internally, raphe ridge bent dorsally, bearing the central slits on a longitudinal thickening | parallel and close to the ventral margin, with almost straight branches deflected ventrally at the centre and with central pores pointing in opposite directions. Internally, raphe on a rib which is turned towards the dorsal side and twists into the vertical position only at the centre and poles. Central raphe slits on a small, elongated nodule |
| Dorsal striae            | more or less radiate at the valve middle, (16–) 17–19 in 10 µm, and becoming much denser, 19–21 in 10 µm, near the apices | parallel in the centre, 20–26 in 10 µm, but clearly radiate and denser at the poles, 24–28 in 10 µm | radiate at the valve middle, 17–20.7 in 10 µm, and much denser at the apices | weakly radial, 10–12.8 in µm, the middle stria is usually missing – at least on the adaxial side – or reduced, not reaching the axial area |
| Ventral striae           | more or less straight at the middle of smaller frustules to radiate in larger ones, (14–)15–17 in 10 µm. At the apices, much denser and relatively parallel, 19–21 in 10 µm | parallel throughout but slightly radiate at the centre, 19–23 in 10 µm at the valve centre, 22–26 in 10 µm at the poles | distinctly radiate in the middle, 16–19.3 in 10 µm, but much denser and parallel at the apices | 10–12.1 in 10 µm and approximately the same size along the whole length of the valve |
| Number of areolae in 10 µm | 55–60                           | 48–52                | 46–50 [not indicated in the original paper but measured from the SEM image Fig. 50 in Danielidis & Mann 2002] | 45–50 [not shown in the original paper but measured from the SEM images Figs 10–11, 13, 15 in Danielidis & Mann 2002] |
| habitat                  | weakly brackish to typical marine, epilithic species | epilithic marine species | marine species | marine species |
adaxial ends of the striae which open to the cell interior;
(7) lower areola density (i.e., 45–50 in 10 µm vs. 55–60 in 10 µm for *S. aegyptiaca*); the terminal areola of some
dorsal striae being occasionally double and frequently
stria discontinuities.

In spite of considerable previous investigations on the
Egyptian inland–water diatoms, which were however
mainly based on LM observations (e.g., Shaaban 1994;
Hamed 2008; Mansour et al. 2015; Khairy et al. 2017), it is
likely that there are still some *Seminavis* species (often
misidentified as *Amphora* in the past) overgrown in the
Egyptian inland–water habitats (A.A.S., unpublished
data). These need to be studied well using both LM and
SEM to accurately describe their taxonomic characteristics.
In agreement with this hypothesis, the study of
El–Shaheed (2006) on the diatom flora of the periphytic
assemblages of the west coast of the Red Sea and Suez
Gulf revealed two diatom species belonging morphologi-
cally to the genus *Seminavis* but unfortunately there is no
information available on their morphotaxonomic features.
‘*Seminavis* sp.’ in his study (El–Shaheed 2006, plate
II, fig. 4) bears some resemblance with *S. aegyptiaca*.

From the ecological point of view, *Seminavis
aegyptiaca* was so far only recorded from the estuary of
the River–Nile Damietta Branch, and therefore de-
tailed information about its autecological preferences
is still lacking. However, there is a strong indication
that it prefers typical marine waters, with only a weak
tendency to extend into brackish waters. The prefer-
ence of *Seminavis* species identified so far for brackish
and marine habitats is well known and reported in the
literature (e.g., Round et al. 1990; Danielidis & Mann
2002, 2003; Garcia 2007; Wachinicka & Gaiser 2007;
Álvarez–Blanco & Blanco 2014; Talgatti et al.
2014; Rioual et al. 2014; De Decker et al. 2018). More
interestingly, at the type locality, the new species showed
a considerable tolerance to high nutrient (N, P) levels, as
well as to high concentrations of several heavy metals.
Nutrient–enrichment tolerance was confirmed also by the
c–occurring diatom species.

**Acknowledgements**

This work was a part of the PhyBiO project funded by the Italian
Ministry of Foreign Affairs and International Cooperation (MAECI)
to the MUSE Post–Doc Abdullah A. Saber for the academic year
2018/2019. These results were presented at the 24th International Diatom
Symposium, Université Laval, Quebec City, Canada, August 21–26
2016. Authors are deeply grateful to the Botany and Microbiology
Department, Faculty of Science, Al–Azhar University, Cairo (Egypt),
and also to the Botany Department, Faculty of Science, Ain Shams
University (Egypt) for providing all facilities used for this research.
Also, we are very thankful to Dr Nicola Angeli (MUSE Museo delle
Scienze, Limnology & Phycology Section, Trento, Italy) for his kind
support in taking SEM images.

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