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Eunotia (Bacillariophyta) biodiversity from high altitude, freshwater habitats in the Mugecuo Scenic Area, Sichuan Province, China

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Abstract

Mugecuo Scenic Area is located in the northern Hengduan Mountains between the Sichuan Basin and the Qinghai-Tibet Plateau and has a subtropical humid monsoon climate. The area is at an altitude of 2600–3800 m above sea level (asl), with water originating mostly from melting mountain snow. In the region, a total of 20 *Eunotia* species have been identified, including two new species: *E. mugecuo sp. nov.*, consisting of valves arched, clavate, ends broadly rounded, and terminal raphe fissures at the junction between valve face and mantle. The other newly-identified species is classified named as *E. filiformis sp. nov.*, consisting of valves gently bent, ends not noticeably or only slightly inflated, broadly rounded, with external terminal raphe fissures curving in an angle of 180° back from apical nodules. Five newly recorded species have been identified in China, including *E. odebrechtiana*, *E. michaelis*, *E. pomeranica*, *E. pseudogroenlandica* and *E. superpaludosa*. Here, we discuss the new species and new taxon records through light and scanning microscopic documentation of valve morphology, along with key internal and external valve characteristics, and analyze the distribution of *Eunotia* in the Mugecuo Scenic Area.

Keywords: Diatom, *Eunotia*, Mugecuo, new species, taxonomy

Introduction

Eunotia (Ehrenberg, 1837) is a large genus consisting of greater than 800 species that is mostly restricted to freshwater environments (Novitski *et al*., 2005). This genus is abundant in the epiphyton of oligotrophic waters with low conductivity levels and in highly transparent water bodies (Round *et al*., 1990; Patrick & Reimer, 1996; Qi & Li, 2004; Liu *et al*., 2011). The *Eunotia* taxa comprises diverse morphological types, some of which have been recently classified into different genera (Metzeltin & Lange-Bertalot, 2007; Wetzel *et al*., 2012; Burliga *et al*., 2013; Pavlov & Levkov 2013). Most *Eunotia* species are asymmetrical with regard to the apical axis, with external punctate striae evident but interrupted near the ventral portion of the valve. The raphe is predominantly on the valve mantle extending onto the valve face. The girdle is composed of numerous punctate bands. At present, a total of 138 species of *Eunotia* have been reported in China, with six newly described species: *Eunotia sudeticiformis* Kociolek, You, Stepanek, Lowe & Wang (Kociolek *et al.,* 2016: 288); *Eunotia anhuiensis* Yang (Yang, 1995: 206); *Eunotia hainanensis* Zhang & Qi (Zhang & Qi, 1993: 80); *Eunotia parallela* f. *asiatica* Skvortzow (Skvortzow, 1938: 346); *Eunotia monodon* var. *koreana* f. *undulata* Skvortzow (Skvortzow, 1938: 344); and *Eunotia major* var. *asiatica* Skvortzow (Skvortzow, 1930: 40).

Mugecuo is located in Kangding County, Sichuan Province, China in the northern Hengduan Mountains between the Sichuan Basin and the Qinghai-Tibet Plateau (Chen *et al*., 2013). This area is in a subtropical humid plateau climate zone, with lake water originating mostly from melting mountain snow (Liu *et al*., 1996). Mugecuo Scenic Area is 350 km^2, with a water area of nearly 4 km^2 and a water depth of more than 70 m. Water transparency is typically 6 m. Mountain lakes, such as the ones in this area, that contain high concentration of dissolved silicate and have not been subject to any anthropological effects, are optimal habitats for the vast majority of *Eunotia* taxa (Liu *et al*., 2011; Furey *et al*., 2011).

The purpose of this study was to investigation of *Eunotia* diversity in the Mugecuo Scenic Area. In the this text, we formally described two new *Eunotia* species (*E. mugecuo sp. nov.* and *E. filiformis sp. nov.*), five newly recorded species in China, along with other *Eunotia* taxa found in the Mugecuo Scenic Area. We compared new species with

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other species and the newly recorded species with published literature. Overall, we provide morphological, ecological, and distributional information for the two new species and the five newly recorded species for China.

Materials and methods

Collection sites: A total of 54 composite diatom samples consisting of attached to stone, filamentous algae, aquatic plants, or other flocculent substance floating on the water were collected from mountain lakes, streams, and/or a hot spring in August 2015 in the Mugecuo Scenic Area (30°10′15″ N, 101°52′24″ E) at an altitude of 2600–3780 m. Samples were collected from locations with pH values ranging from 6.8–8.0, with varying water temperatures (lakes: 12.5–13°C; streams: 8.5–21°C; and the hot spring: 30.5°C) and distribution of sites (Fig. 1). Sample numbers (Table 1) indicate the presence of *Eunotia* taxa. Water temperature and pH were measured *in situ* with a YSIPro Plus multi-parameter meter (YSI, Ohio, USA). For sample collection we used toothbrushes, tweezers, and turkey basters.

TABLE 1. Sampling sites and their geographical and chemical characteristics.

Sample number	Collection site	Habitat	Longitude and latitude	Altitude (m asl)	WT (°C)	pH	Conductivity (Ms/cm)
SC201508032	Stream	Epilithic	E 101°51′32″ N 30°08′38″	3800	8.5	6.8	34.5
SC201508034	Stream	Epilithic	E 101°51′32″ N 30°08′38″	3800	8.5	6.8	34.5
SC201508036	Mugecuo Lake	Epiphytic	E 101°51′35″ N 30°08′43″	3780	12.5	7.8	35
SC201508039	Mugecuo Lake	Epilithic and filamentous algae	E 101°51′35″ N 30°08′43″	3780	12.5	7.8	35
SC201508040	Mugecuo Lake	Epilithic	E 101°51′35″ N 30°08′43″	3780	12.5	7.8	35
SC201508042	Mugecuo Lake	Epilithic	E 101°51′35″ N 30°08′43″	3780	12.5	7.8	35
SC201508045	Yao Pool	Epiphytic	E 101°51′42″ N 30°08′57″	3700	13	7.5	30
SC201508052	Hot Spring	Epilithic	E 101°52′08″ N 30°10′14″	3700	30.5	8.0	612
SC201508059	Stream	Filamentous algae	E 101°52′08″ N 30°10′14″	3700	21	——	193
SC201508063	Qisehai Lake	Filamentous algae	E 101°52′26″ N 30°11′13″	3570	——	——	——
SC201508074	Qisehai Lake	Floating floc and filamentous algae	E 101°52′26″ N 30°11′13″	3570	——	——	——
SC201508075	Qisehai Lake	Filamentous algae	E 101°52′26″ N 30°11′13″	3570	——	——	——
SC201508079	Qisehai Lake	Floating floc and filamentous algae	E 101°52′26″ N 30°11′13″	3570	——	——	——
SC201508081	Qisehai Lake	Floating viscous and filamentous algae	E 101°52′26″ N 30°11′13″	3570	——	——	——

Processing and observations: Samples were treated in the laboratory with concentrated nitric acid using the Microwave Accelerated Reaction System (Model MARS, CEM Corporation, Charlotte, NC, USA) and a pre-programmed digestion scheme (temperature: 180°C, ramp: 15 min, hold: 15 min). Cleaned diatoms were mounted in Naphrax® as following the procedure described in You *et al*. (2017) for light microscopy (LM) analysis or otherwise spread on aluminum foil and mounted onto stubs for scanning electron microscopy (SEM). LM observations were made with an Olympus BX53 microscope fit for DIC optics (100 × objective, numerical aperture 1.4), and SEM examination was conducted using a Hitachi SU 8010 scanning electron microscope (2 kV) (Hitachi, Tokyo, Japan). Terminology and identifications were based on a number of previous publications (Hustedt, 1930; Cleve-Euler, 1953; Gasse, 1986; Hartley, 1996; Lange-Bertalot & Metzeltin, 1996; Metzeltin & Lange-Bertalot, 1998; Lange-Bertalot & Genkal, 1999; Rumrich *et al*., 2000; Zhu & Chen, 2000; Metzeltin & Lange-Bertalot, 2002; Krammer & Lange-Bertalot, 2004; Qi & Li, 2004; Werum & Lange-Bertalot, 2004; Metzeltin *et al*., 2005, Siver *et al*., 2005; Liu *et al*., 2011; Lange-Bertalot *et al*., 2011).

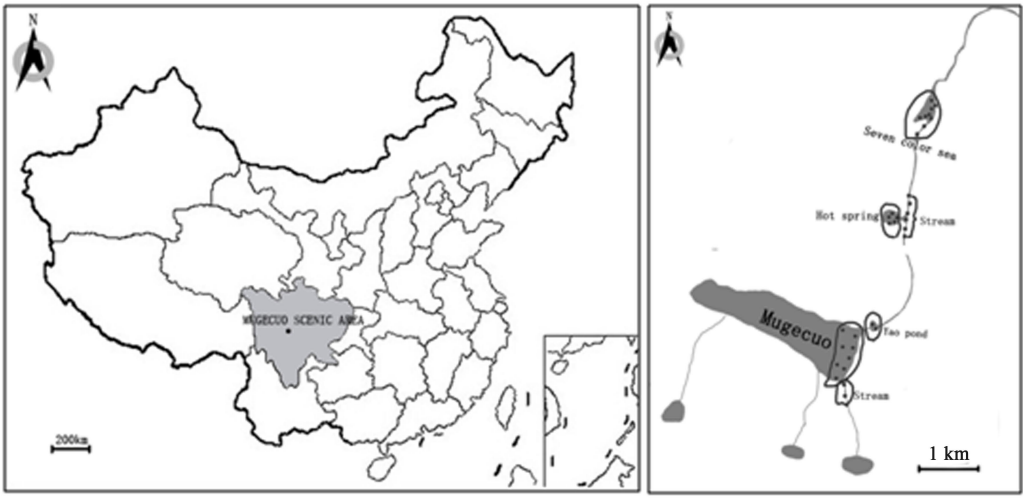


FIGURE 1. Location of Mugecuo Scenic Area. Distribution of sample collection sites are indicated by black dots.

Results

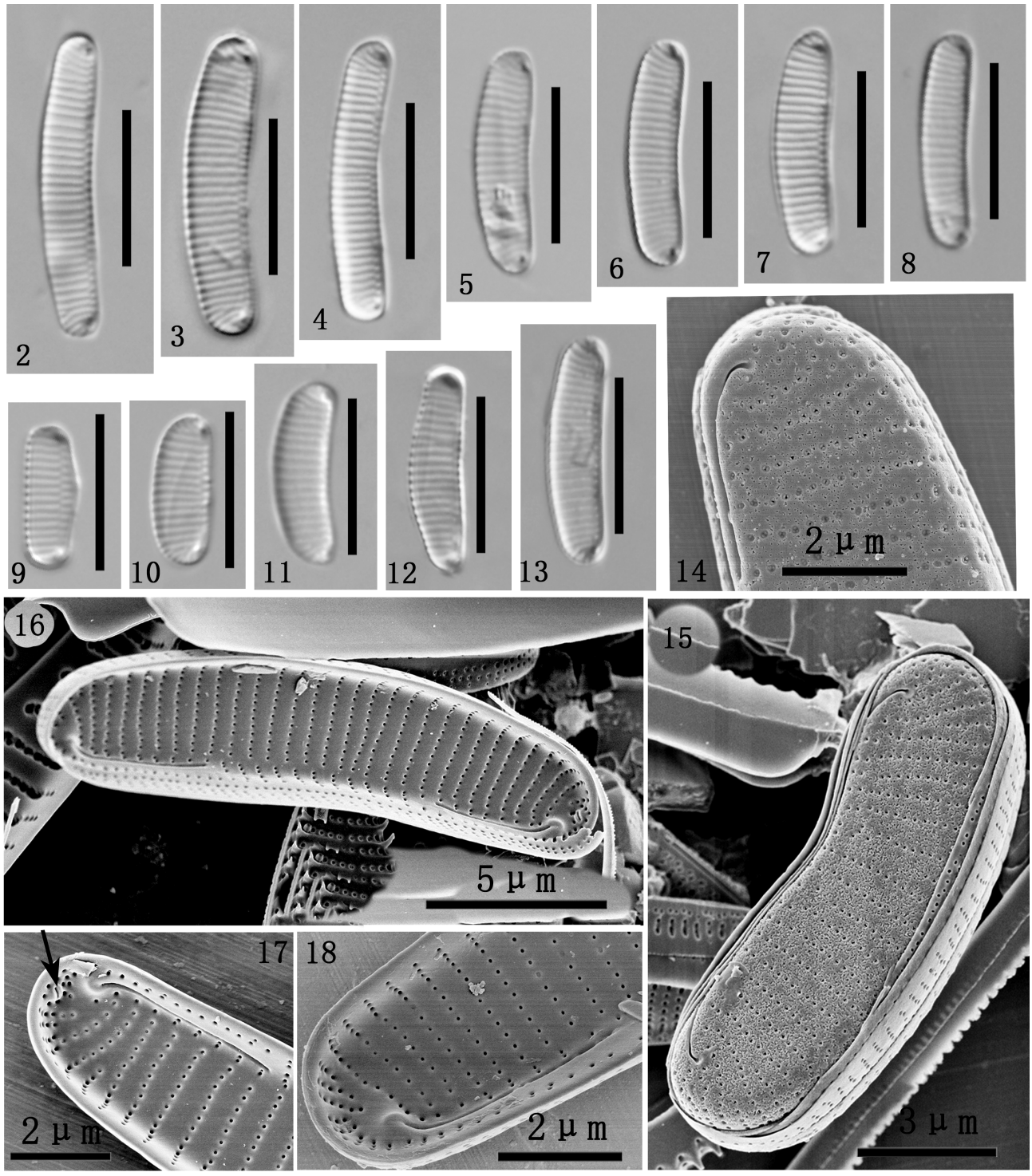
A total of 20 taxa have been identified in the Mugecuo Scenic Area, including two new species, *E. mugecuo sp. nov.* and *E. filiformis sp. nov.* In addition, there have been five newly recorded species in China, *E. odebrechtiana* Metzeltin & Lange-Bertalot (Metzeltin & Lange-Bertalot, 1998: 71), *E. michaelis* Metzeltin, Witkowski & Lange-Bertalot (Metzeltin & Witkowski, 1996: 14), *E. pomeranica* Lange-Bertalot, Bak & Witkowski (Lange-Bertalot *et al*., 2011: 198), *E. pseudogroenlandica* Lange-Bertalot & Tagliavent (Lange-Bertalot *et al*., 2011: 202), and *E. superpaludosa* Lange-Bertalot (Lange-Bertalot *et al*., 2011: 147). Here, we described valve morphological characteristics of the two new species and the five new records and provided the distribution and ecology of these species. Frustule size and figure number of all of the 20 taxa focused on herein (including the other taxa discussed above) are shown in Table 2.

TABLE 2. *Eunotia* size and plate information.

Taxa	Length (μm)	Breadth (μm)	Striae (in 10 μm)	Fig.
E. mugecuo F. Luo, Q-M. You & Q-X. Wang	9–23	3–4	18–20	2–18
E. filiformis F. Luo, Q-M. You & Q-X. Wang	86–100	3–3.5	15–18	19–27
E. bigibboidea Lange-Bertalot & Witkowski	36	13	10	103
E. bilunaris Ehrenberg & Schaarschmidt	45–58	3–3.5	15–18	98–99
E. circumborealis Lange-Bertalot & Norpel-Schempp	25	6	11	92
E. glacialispinosa Lange-Bertalot & Cantonati	92–94	5–6	12–13	80–81, 105
E. michaelis Metzeltin, Witkowski, & Lange-Bertalot	14–22	4–5.5	13–16	47–54
E. minor Kutzing & Grunow	30–43	5–6	11–12	86–89
E. monnieri Lange-Bertalot	45	3	17	98–99
E. nägelii Migula	87–90	3–3.5	16–17	100–101
E. nymanniana Grunow	26–40	2.5–3	17–20	93–95
E. odebrechtiana Metzeltin & Lange-Bertalot	36–44	6–8	5–7	38–38
E. palatina Lange-Bertalot & Krüger	20	5	18	91
E. parallela Ehrenberg	45–50	6	11–13	86–89
E. pomeranica Lange-Bertalot & Witkowski	28–35	5–6	14–16	39–46
E. pseudogroenlandica Lange-Bertalot & Tagliaventi	13–19	3–3.5	17–20	55–67
E. pseudopapilio Lange-Bertalot & Norpel-Schempp	37	15	10	102,106
E. scandiorussica Kulikovskiy, Lange-Bertalot, Genkal, & Witkowski	21	4	18	90
E. soleirolii Kutzing & Rabenhorst	50–53	5–6	11–12	82–83
E. superpaludosa Lange-Bertalot	33–54	4–5	14–18	68–79

Eunotia mugecuo *sp. nov.* (Figs 2–18; holotype = Fig. 6)

Valves arched, clavate, dorsal margin slightly curved or straight in the smaller specimens, ventral margin moderately concave to straight and almost parallel to the dorsal margin, ends broadly rounded, length 9–23 μm, and breadth 3–4 μm. Striae parallel at the center of the valve, becoming radial at the ends, 18–20/10 μm. Areolae indistinct under LM. In SEM, external raphe fissures at the junction between valve face and mantle and terminal raphe fissures extend slightly onto the valve face (Figs 14–15). Areolae rounded, ca. 50/10 μm (Figs 15–16). Internal valve view shows one sesile rimportula present at one apex, with a large opening (Figs 16–18).



FIGURES 2–18. *E. mugecuo sp. nov.*. 2–13. LM images; 6. Holotype; 14–18 SEM images; 14. External valve end; 15. External valve view; 16. Internal valve view; 17–18. Terminal ends of internal valve, arrow show a rimoportula. LM scale bars, 10 μm.

Locality: China. Sichuan Province: Mugecuo Scenic Area, 30º10′15″N, 101º52′24″E. This new species was found in Qisehai Lake, collected by Q-X. Wang, J-G. Cao, & Y. Cao *et al*. in August 2015.

Holotype: SHTU! slide and material SC201508079, Biology Department Diatom Herbarium, Shanghai Normal University, Shanghai, China, here illustrated as Fig. 6.

Isotypes: COLO! material 628100, University of Colorado, Museum of Natural History Diatom Herbarium, Boulder, USA.

Etymology: The species is named for its type locality within Mugecuo Scenic Area.

Remarks: *E. mugecuo sp. nov.* is similar to *E. faba* (Ehrenberg) Grunow (Lange-Bertalot *et al*., 2011: 97) and *E. botuliformis* Wild, Nörpel & Lange-Bertalot (Lange-Bertalot, 1993: 29). *E. mugecuo* differs from *E. faba* mainly in the latter's valve being longer and wider, as well as a notch on the ventral side, and it occasionally appears weakly broadly nose-like (Lange-Bertalot *et al*., 2011). The apices of *E. mugecuo* are obviously broader than *E. botuliformis* (Lange-Bertalot, 1993).

Habitats: This species has been identified in two samples from Qisehai Lake (sample numbers: SC201508079 and SC201508081)**.** The collected material was a mixture of floating viscous or flocculent substance and filamentous algae. This species was rare in our samples, as only 1–2 were observed in a slide.

Distribution: China (This paper)

Eunotia filiformis sp. nov. (Figs 19–27; holotype = Fig. 21)

Valve gently bent, ventral and dorsal margins parallel, ends not noticeably or only slightly inflated, broadly rounded. Length 86–100 μm, breadth 3–4 μm. Striae straight and parallel on the entire valve, 15–18/10 μm (Fig. 27). Under SEM, striae uniseriate, areolae round with polygonal velum, 40–50/10 μm (Fig. 26). External valve proximal raphe fissures at the junction between valve face and mantle, terminal raphe fissures curving in an angle of 180° back from apical nodules on the valve (Figs 25–26). Internal valve showed a hyaline field in the position of external terminal raphe fissures, a single rimportula at one apex of a valve (Figs 23–24).

Locality: China. Sichuan Province: Mugecuo Scenic Area, 30º11′13″N, 101º52′26″E. The new species was found in Mugecuo Lake, collected by Q-X. Wang, J-G. Cao, & Y. Cao *et al*. in August 2015.

Holotype: SHTU! slide and material SC201508039, Biology Department Diatom Herbarium, Shanghai Normal University, Shanghai, China, here illustrated as Fig. 21.

Isotypes: COLO! Material 629039, University of Colorado, Museum of Natural History Diatom Herbarium, Boulder, USA.

Etymology: This species is named for its slim valve.

Remarks: Lange-Bertalot *et al.* (2011) identified this species as *Eunotia.* aff. *E. julma* Lange-Bertalot (Lange-Bertalot *et al*., 2011: 130)*,* and aff. *E. latitaenia* Kobayasi, Ando & Nagumo (Kobayasi *et al*., 1981: 100)*. Eunotia* aff. *E. julma* and aff. *E. latitaenia* are not in line with international nomenclature. Moreover, Lange-Bertalot did not give a formal description and instead only provided photographs for this species. Therefore, we described this species in detail as *E. filiformis* sp. nov.

E. filiformis has a more narrow valve and more dense striae compared to *E. julma* (breadth 4.5–5 μm, striae 14–16/10 μm) (Lange-Bertalot *et al*., 2011)*. E. filiformis* differs from *E. latitaenia* (breadth 5–7 μm, striae 11–14/10 μm) (Kobayasi *et al*., 1981) by the narrower valves, denser striae, and by the consistently shorter terminal raphe fissure (Lange-Bertalot *et al*., 2011). In addition, the difference between *E. filiformis* and *E. gallica* Lange-Bertalot & Witkowski (Lange-Bertalot *et al*., 2011: 108) is that *E. gallica* (Length 90–180 μm, breadth 4–4.7 μm)has a wider valve and more pronounced end (Lange-Bertalot *et al*., 2011).

Habitats: The collected material was a mixture of epiphytic (i.e., filamentous algae) and epilithic material in Qisehai Lake. Sample number: SC201508039. This species was rare in our sample, with only 3–5 observations in a slide.

Distribution: Finland (Lange-Bertalot *et al*., 2011); China (This paper)

Eunotia odebrechtiana Metzeltin & Lange-Bertalot, 1998: 71, figs 56: 1–6, 13, 14 (Figs 28–38)

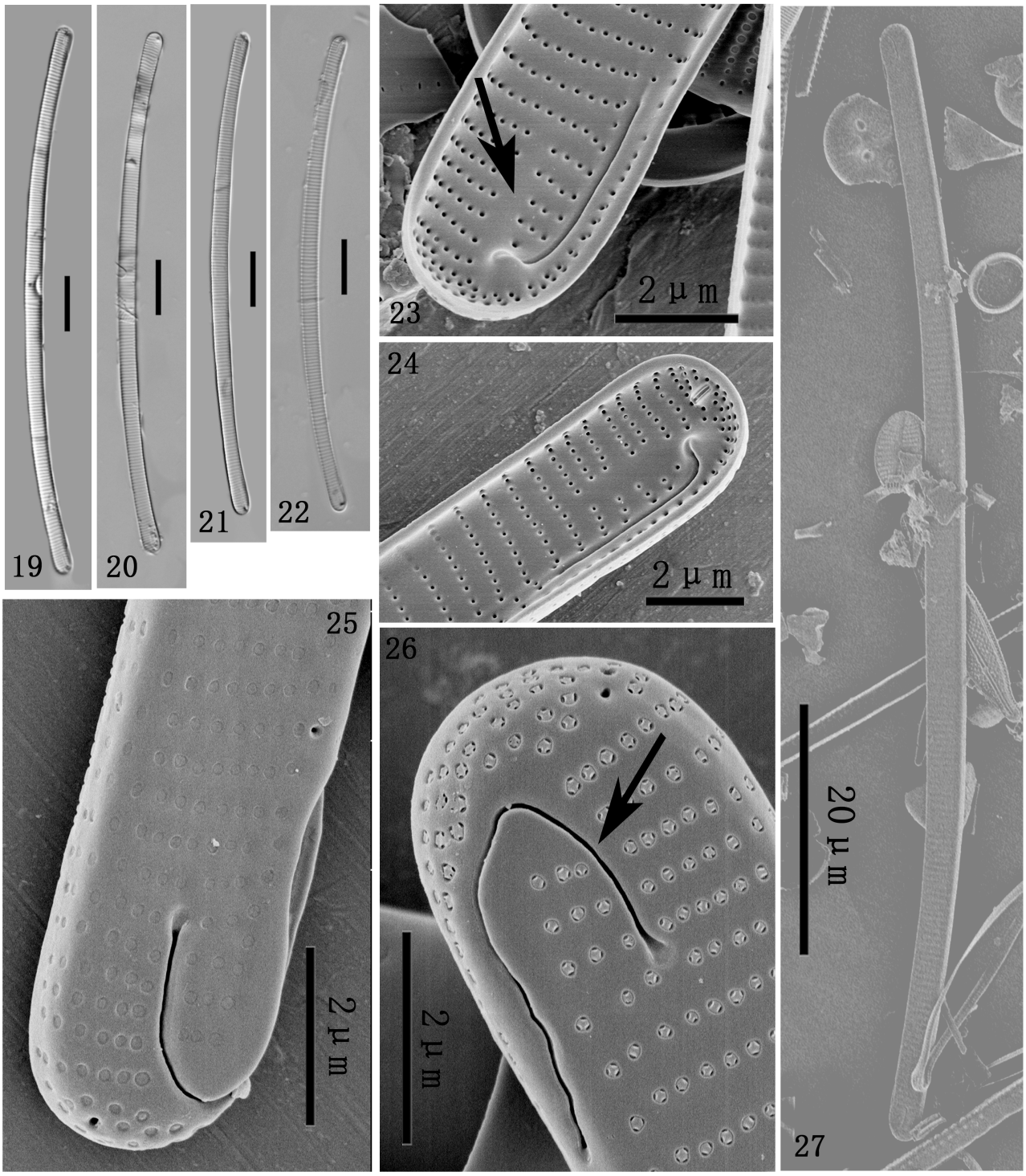
Valve arched, dorsal margin convex, ventral margin moderately concave to almost straight in the middle, ends broadly rounded, length 35–44 μm, and breadth 6–8 μm. In SEM striae are uniseriate, 5–7/10 μm at mid-valve and up to 11–14/10 μm near the apices (Figs 36–37). Dorsal mantle with 1–4 short striae between two long striae (Fig. 38). Areolae round, ca. 45/10 μm. Terminal raphe fissure oblique to the valve (Fig. 37).

Remarks: Compared to the type material, our specimen had an obviously more narrow valve. Description of the type species: length 30–85 μm, breadth 8–13 μm, striae 4–7.5/10 μm. All other features were the same, especially the

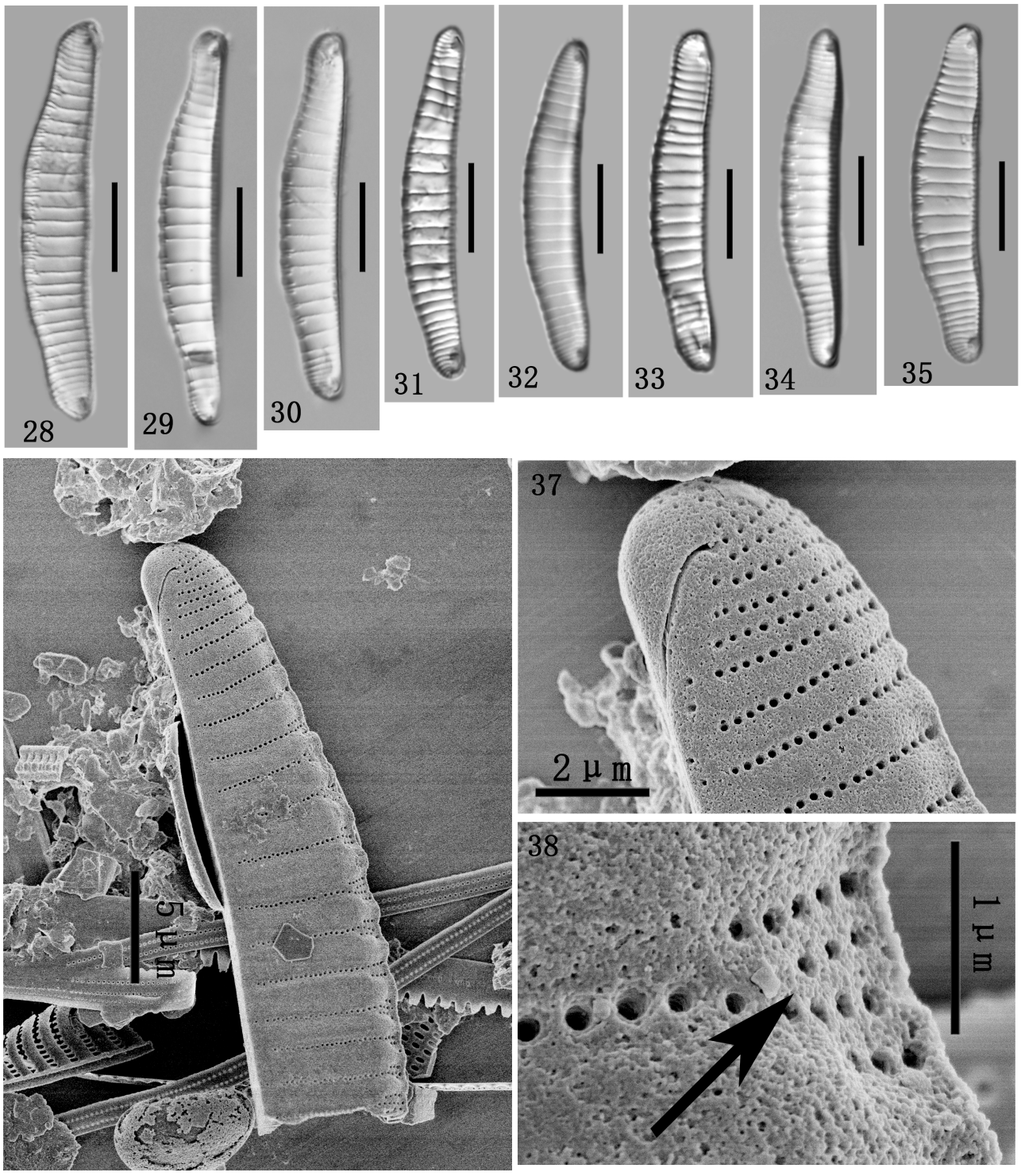
dispersed striae in the valve and short striae on the dorsal mantle. These features are unique to *E. odebrechtiana* in comparison to other species of the genus.

Habitats: Epilithic in streams and Mugecuo Lake and epiphytic (i.e., as filamentous algae) in Qisehai Lake. Sample numbers: SC201508032, SC201508034, SC201508042, and SC201508075.

Distribution: South America (Metzeltin & Lange-Bertalot 1998); China (This paper).



FIGURES 19–27. *E. filiformis* sp. nov. 19–22. LM images; 21. Holotype; 23–27. SEM images; 23–24 Terminal ends of internal valve, arrow show a hyaline areas; 25–26. Terminal ends of external valve, arrow show terminal raphe fissures ; 27. External valve view. LM scale bars, 10 μm.



FIGURES 28–38. *E. odebrechtiana*. 28–35. LM images; 36–38. SEM images; 36. Half external valve view; 37. Terminal ends of external valve; 38. Arrow show short striae of mantle in the middle. LM scale bars, 10 µm.

Eunotia pomeranica Lange-Bertalot & Witkowski in Lange-Bertalot *et al*., 2011: 198, figs 224: 1–13; 225: 1–15; 226: 1–5 (Figs 39–46)

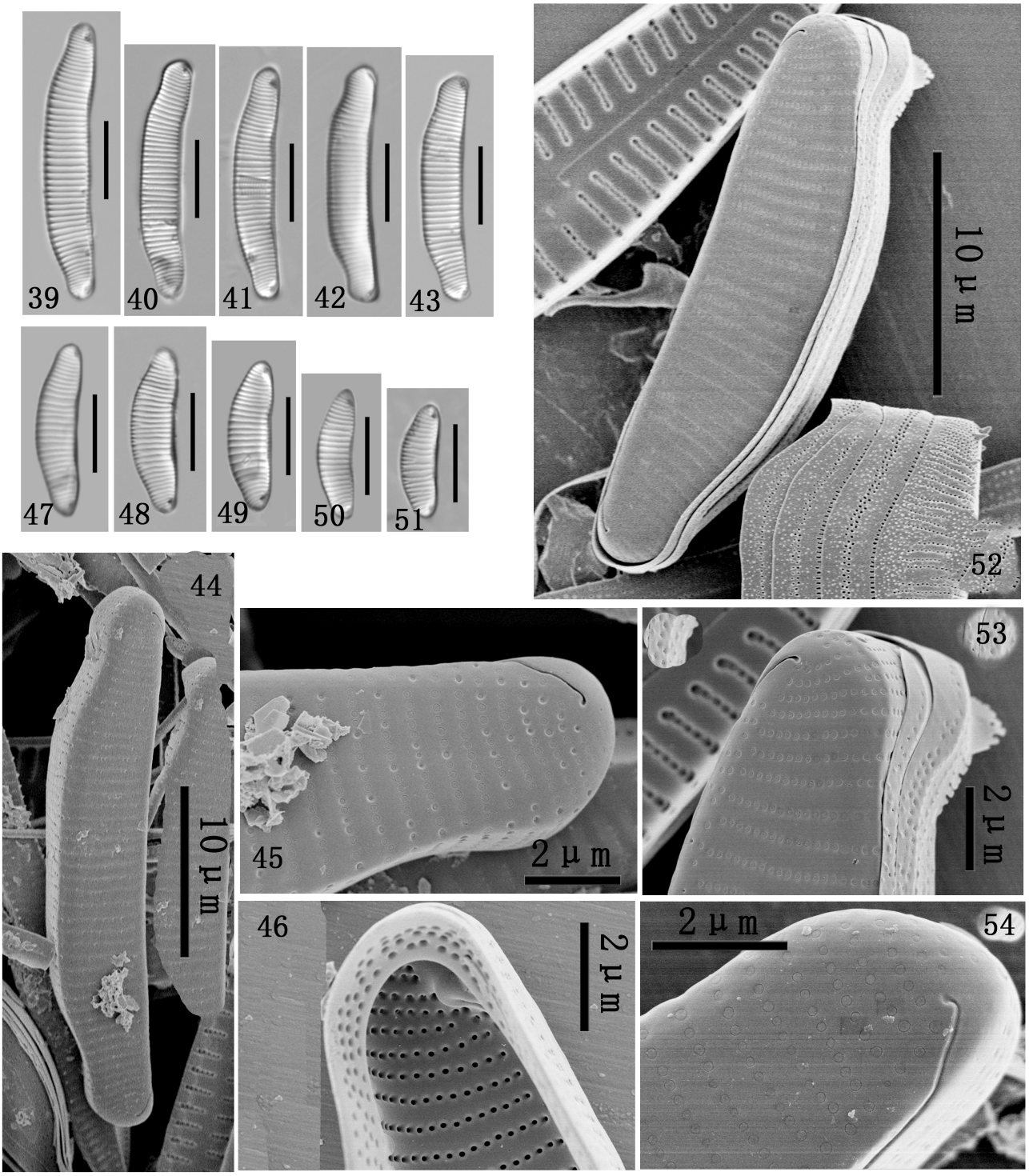
Valve arched, dorsal margin convex, ventral margin moderately concave to almost straight and parallel dorsal margin proximally, ends broadly rounded, length of 28–35 µm, and breadth of 5–6 µm. In SEM: striae uniseriate and in parallel at middle valve, becoming radial at apices (Fig. 44), with 13–16/10 µm, and up to 18–20/10 µm near apices. Areolae round, ca. 40/10 µm. Terminal raphe ends oblique to the polar end (Figs 45–46).

Remarks: The type material comprises two different forms, a larger and a smaller form. The species in our samples is more similar to the smaller taxa of the type material, with a description that includes a length of 24–75 µm,

breadth of 6–9 μm, and striae of 11–15/10 μm (Lange-Bertalot *et al*., 2011). In Poland, the species was found in Piaski Lake, which consists of a sandy underground that contains $CaCO_3$ (Lange-Bertalot *et al*., 2011). The habitat of Qisehai Lake is similar to Piaski Lake (Chen *et al*., 2013).

Habitats: Epiphytic on filamentous algae and floating viscous or flocculent substance in Qisehai Lake. Sample numbers: SC201508075, SC201508079, and SC201508081.

Distribution: Poland (Lange-Bertalot *et al*., 2011), China (This paper)



FIGURES 39–54. *E. pomeranica*. 39–43. LM images; 44–46. SEM images; 44. External valve view; 45. Terminal ends of external valve; 46. Terminal ends of internal valve. Figs 47–54: *E. michaelis*. 47–51. LM images; 52–54. SEM images; 52. External valve view; 53–54. Terminal ends of external valve. LM scale bars, 10 μm.

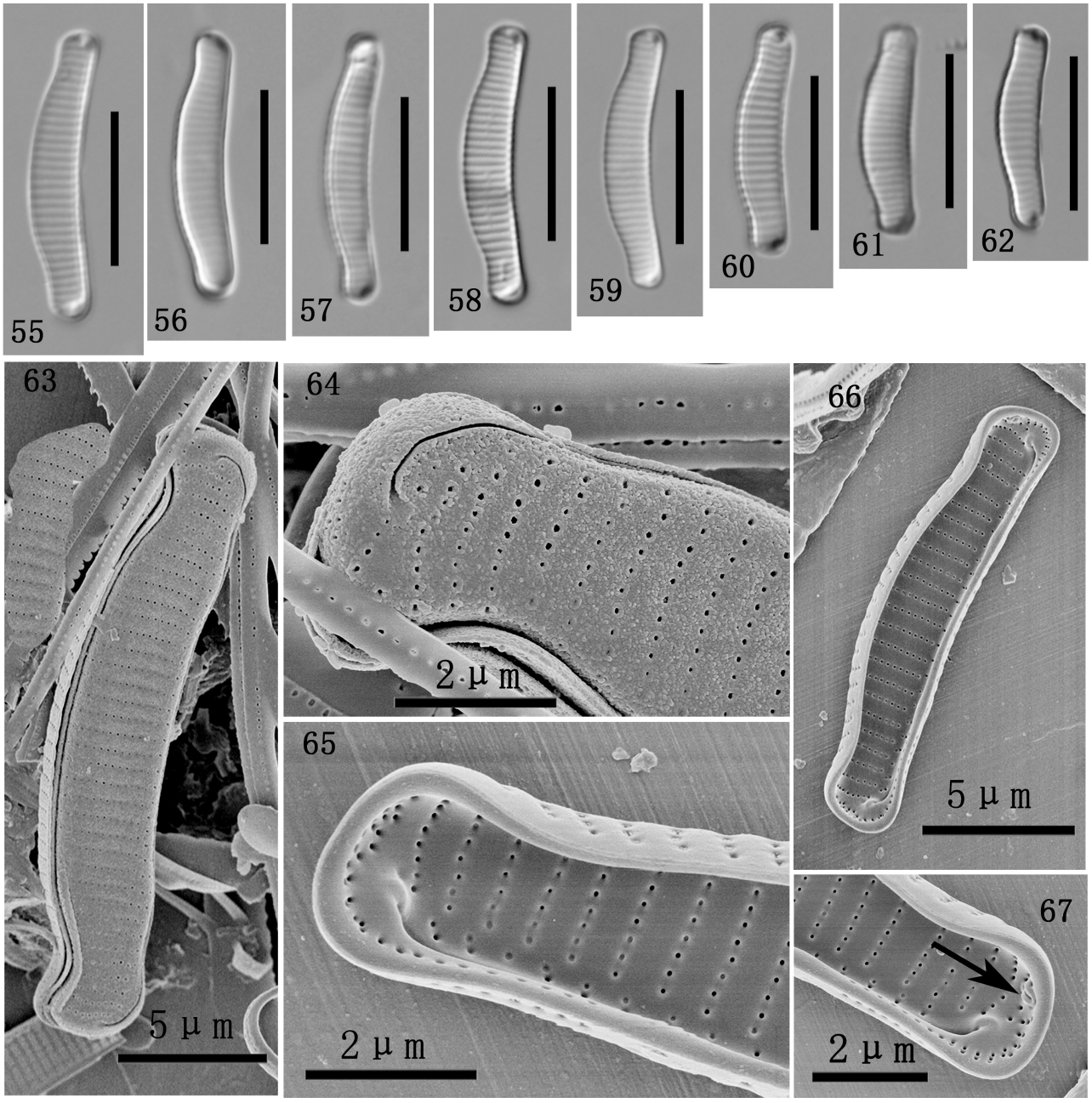
Eunotia michaelis Metzeltin, Witkowski & Lange-Bertalot in Metzeltin & Lange-Bertalot, 1996: 14, figs 34: 2–8; figs 70: 18, 19; figs 90: 5–6.

Valve arched, strong convex dorsal margin, ventral margin moderately concave to almost straight proximally, apices slightly or barely protracted and broadly rounded, length of 14–22 μm, and breadth of 4–5.5 μm. SEM striae are uniseriate 13–16/10 μm and near the ends up to 17–18/10 μm. Areolae appear round, 40–45/10 μm. Terminal raphe fissure oblique to the poles, ca. 1 μm visible on valve face (Figs 52–54).

Remarks: Compared to the type material, the valves in our samples are slightly longer and narrower, and striae are denser. The description of *E. michaelis* is as follows: length of 16–20 μm, breadth of 4.5–6 μm, and striae 12–16/10 μm. Previously, this species has been found in *Sphagnum* peat bogs in sub-Artic Beer Island and European Russia. Populations were abundant at both locations (Metzeltin & Lange-Bertalot, 1996), which varies from the habitats studied herein.

Habitats: Epiphytic on filamentous algae or floating viscous in Qisehai Lake. Sample numbers: SC201508075, SC201508079, and SC201508081.

Distribution: Germany (Metzeltin & Lange-Bertalot, 1996), Russia (Lange-Bertalot *et al*., 2011), China (This paper).



FIGURES 55–67. *E. pseudogroenlandica*. 55–62. LM images; 63–67. SEM images; 63. External valve view; 64. Internal valve view; 66. Terminal ends of external valve; 65, 67. Terminal ends of internal valve, arrow show a rimoportula. LM scale bars, 10 μm.

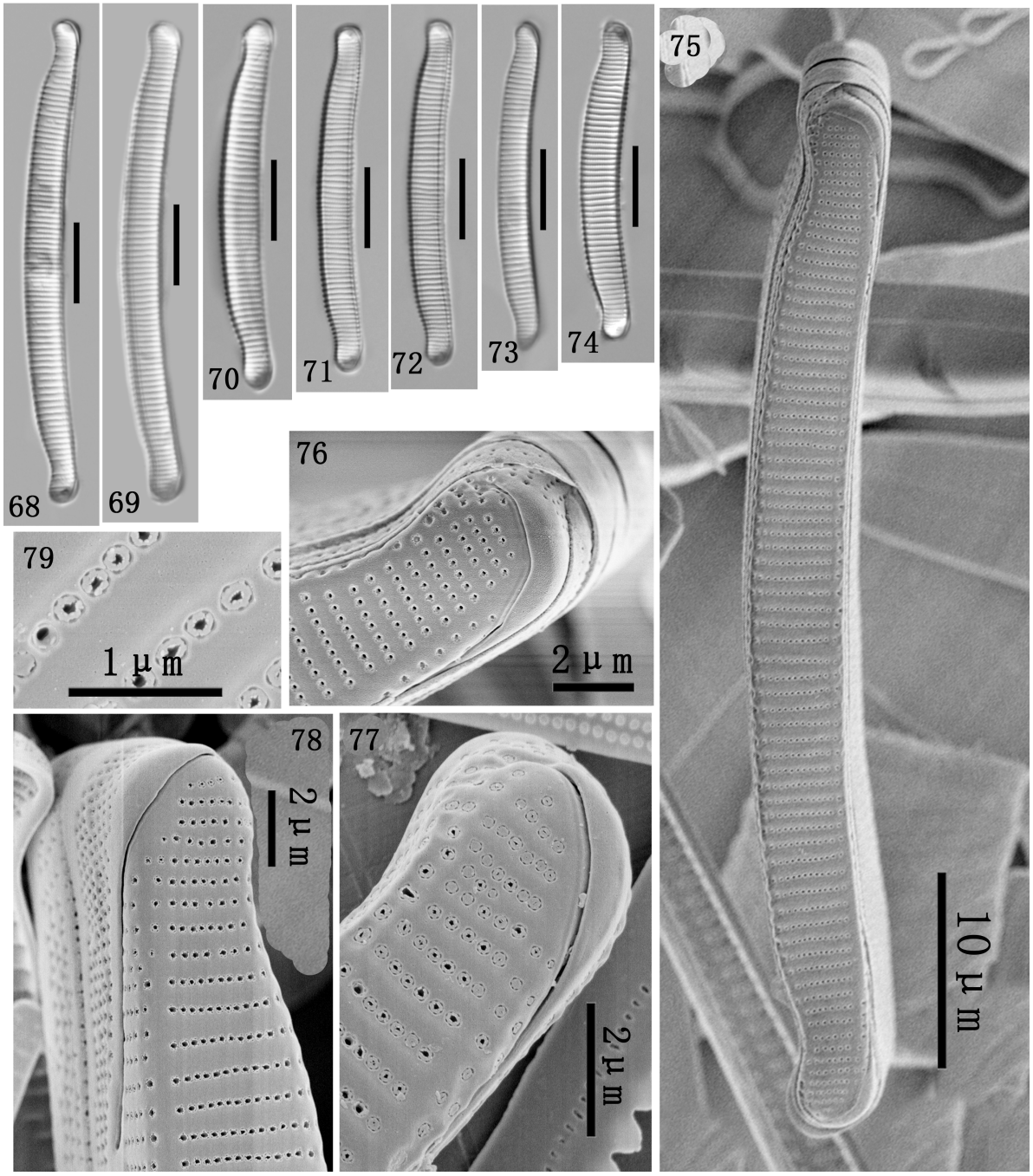
Eunotia pseudogroenlandica Lange-Bertalot & Tagliaventi in Lange-Bertalot *et al*., 2011: 202, figs 132: 1–67; figs 133: 1–11. (Figs 61–71, 77–81)

Valves are small and arched, dorsal margin clearly convex, ventral margin slightly concave or straight, apices reflected and bluntly rounded, length of 13–19 μm, breadth of 2.5–3.5 μm. SEM striae are uniseriate, 17–20/10 μm. Areolae appear round, ca. 45/10 μm (Figs 63–64). Terminal raphe fissures bend toward the dorsal margin (Fig. 64). The internal valve view shows one helictoglossa near the polar end (Figs 65–67).

Remarks: The valve is similar to the type species (Lange-Bertalot *et al*., 2011), whereas the striae are more dense in our samples. The protologue of *E. pseudogroenlandica* is as follows: length of 12–36 μm, breadth of 2.7–3.6 μm, striae of 15–18/10 μm.

Habitats: Epilithic in Mugecuo Lake or epiphytic on filamentous algae or floating viscous in Qisehai Lake. Sample numbers: SC201508040, SC201508079, and SC201508081.

Distribution: Siberia, Norway, Finland, France, Italy (Lange-Bertalot *et al*., 2011), Macedonia (Pavlov & Levkov, 2013), Germany (Cantonati *et al*., 2010), Netherlands (Veen *et al*., 2015), China (This paper).



FIGURES 68–79. *E. superpaludosa.* 68–74. LM images; 75–79. SEM images; 75. External valve view; 76–78. The ends of the raphe; 79. Areolae and velum. LM scale bars, 10 μm.

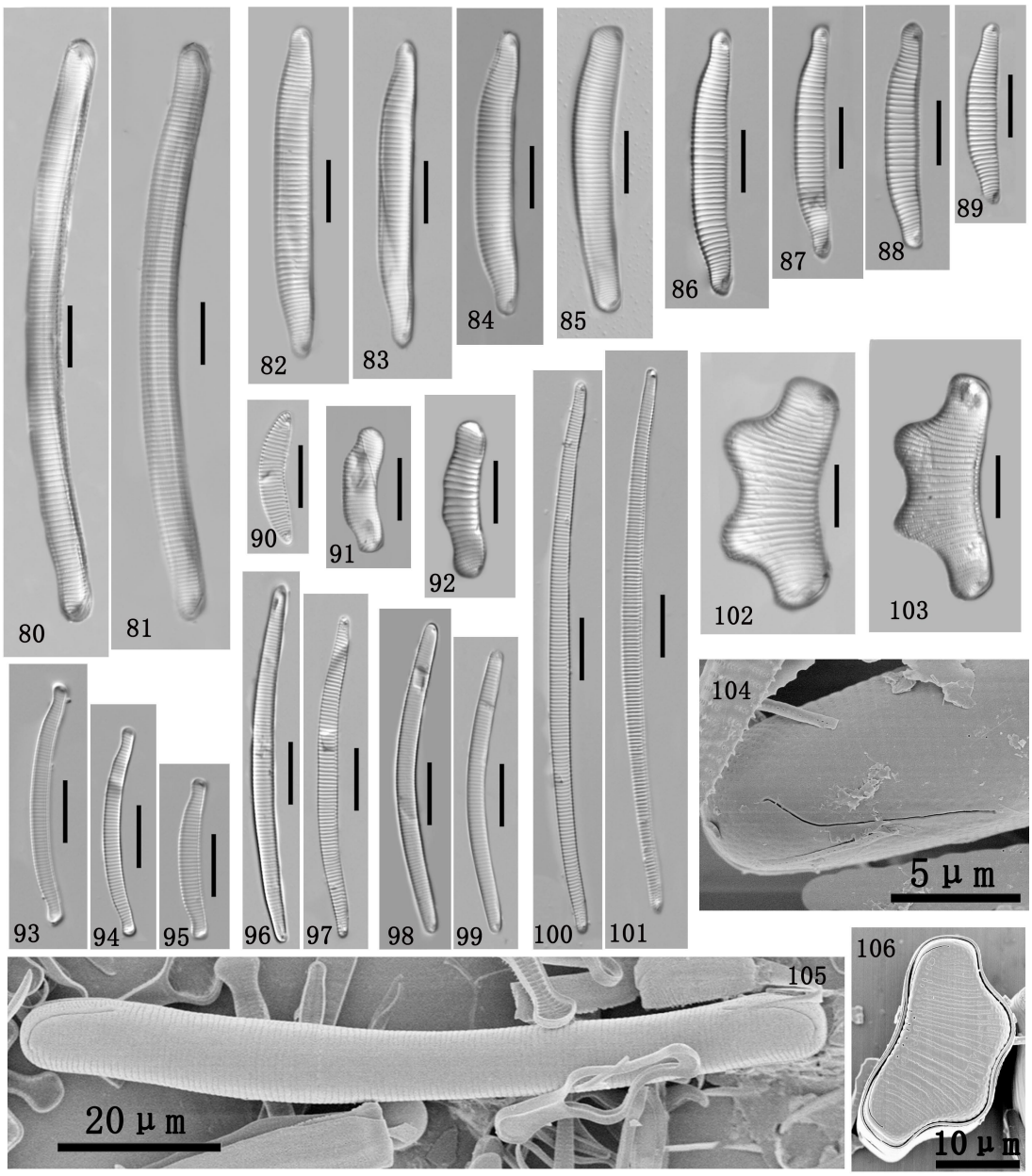
Eunotia superpaludosa Lange-Bertalot in Lange-Bertalot *et al*., 2011: 231, figs 147: 48–58; figs 148: 1–23; figs 149: 1–7 (Figs 68–79),

Valve curved or arched, convex dorsal margin, concave ventral margin, two sides of the valve almost parallel, apices capitated and reflected, length of 33–54 μm, and breadth of 4–5 μm. SEM observations indicate striae are uniseriate, 14–18/10 μm (Fig. 75). Areolae appear round and with hollow disc velum, ca. 40/10 μm. Terminal raphe fissure bend toward the dorsal margin up to ends (Figs 76–78). The striae are more dense on valve mantle (Fig. 78).

Remarks: Compared to the type material (Lange-Bertalot *et al*., 2011), these have similar characters in outline and size, and their terminal raphe fissure bend toward the dorsal margin up to ends. The description of *E. superpaludosa* is as follows: size is length 20–75 μm, breadth 2.4–4 μm. Description of breadth data may not be accurate, as the breadth of this species is approximately 4–5 μm (see pl. 148: Figs 3–5, Fig. 7 from Lange-Bertalot *et al*., 2011). Species in these collected samples have more dense striae on the mantle compared to the type species. Due to the differences in density of the striae on the mantle, these cannot be classified as two species.

Habitats: Epilithic to stones in the stream, epiphytic on filamentous algae or floating viscous in Qisehai Lake. Sample numbers: SC201508034, SC201508079, and SC201508081.

Distribution: North America, Russia (Lange-Bertalot *et al*., 2011), China (This paper)



FIGURES 80–81, 105. *E. glacialispinosa*; 82–84: *E. soleirolii*; 85, 104: *E. parallel*a; 86–89: *E. minor*; 90: *E. scandiorussica*; 91: *E. palatina*; 92: *E. circumborealis*; 93–95: *E. nymanniana*; 96–97: *E. bilunaris*; 98–99: *E. monnieri*; 100–101: *E. nägelii*; 102, 106: *E. pseudopapilio*; 103: *E. bigibboidea*. LM scale bars, 10 μm.

Discussion

Mugecuo Scenic Area is surrounded by mountains, forests, and grasslands. The lakes in this area are clean and not heavily polluted (Chen *et al*., 2013), and studies have shown that this area has a high species richness of diatoms, with a total of 63 genera and 350 species known. Common genera include *Cyclotella* (Kützing) Brébisson (1838), *Fragilaria* Lyngbye (1819), *Staurosira* Ehrenberg (1843), *Cymbella* Agardh (1830), *Gomphonema* Ehrenberg (1832) and *Nitzschia* Hassall (1845). *Eunotia* is one of the largest taxa in this area, with a total of 20 species recognized. More than one-third of *Eunotia* species are described as living in oligotrophic, low-conductivity environments, including *E. bigibboidea* Lange-Bertalot & Witkowski（Lange-Bertalot *et al.* 2011）, *E. bilunaris* (Ehrenberg) Schaarschmidt (Kanitz 1880: 159), *E. glacialispinosa* Lange-Bertalot & Cantonati (Cantonati & Lange-Bertalot 2010: 269), *E. palatine* Lange-Bertalot & Krüger (Werum & Lange-Bertalot 2004: 154), *E. parallela* Ehrenberg (Ehrenberg, 1843: 414), *E. pseudogroenlandica* Lange-Bertalot & Tagliaventi (Lange-Bertalot *et al.,* 2011: 202), *E. soleirolii* (Kützing) Rabenhorst (Rabenhorst, 1864: 74), and *E. superpaludosa* Lange-Bertalot (Lange-Bertalot *et al*., 2011: 231) (Lange-Bertalot *et al*., 2011; Qi & Li, 2004; Werum & Lange-Bertalot, 2004, Liu *et al*., 2011). Results of this study also demonstrate that the preferred habitats for *Eunotia* reflect the characteristics of oligotrophic and low conductivity lakes (detailed data are shown in Table 1).

The number of *Eunotia* diatoms varies among different habitats, and often the highest abundances are found in lakes, total 20 species. Among lake habitats, *E. michaelis*, *E. minor* (Kützing) Grunow (Van Heurck 1881), *E. pomeranica*, and *E. superpaludosa* were relatively abundant with respect to other *Eunotia* species. Only four species were identified from the stream: *E. michaelis*, *E. minor*, *E. parallela,* and *E. pomeranica.* Only one species was found in the hot spring samples, specifically *E. minor*. This species is abundant in acidic waters and is frequently found in springs and headwaters on/in siliceous rocks or soil. It has also been detected in standing water bodies with low conductivity, as well as in peat bogs (Kwandrans, 1993; Furey *et al*., 2009; Lange-Bertalot *et al*., 2011; Pavlov & Levkov, 2013). *E. minor* was found in all three habitats sampled here, suggesting that *E. minor* may have a relatively high habitat tolerance.

Eunotia species are often influenced by pH (Patrick & Reimer, 1966; Liu *et al*., 2011). Most species of *Eunotia* have been reported as acidobiontic or acidophilic organisms with a preference for acidic water (Hustedt, 1937–1939; Patrick & Reimer, 1966; Liu *et al*., 2011). The pH of the waters in the Mugecuo region ranges from 6.8 to 8.0. In previous reports (Lange-Bertalot *et al*., 2011; Liu *et al*., 2011), *E. bigibboidea, E. bilunaris, E. circumborealis* Lange-Bertalot & Nörpel (Lange-Bertalot, 1993: 30), *E. glacialispinosa, E. monnieri* Lange-Bertalot & Tagliaventi (Lange-Bertalot *et al*., 2011: 161), *E. pseudogroenlandica, E. scandiorussica* Kulikovskiy, Lange-Bertalot, Genkal & Witkowski (Kulikovskiy *et al*., 2010: 95) and *E. näegelii* Migula (Migula, 1905: 203) have been reported to prefer acidic environments. These species have also been found in the Mugecuo region, indicating that *Eunotia* species can not only be found in acidic environments, but they may also tolerate and thrive in clean, slightly alkaline bodies of water. Our research shows that the pH tolerance of these species is broader than has previously been believed. We also show that the geographical distribution of some species, such as *E. odebrechtiana*, *E. michaelis*, *E. pomeranica* and *E. superpaludosa*, is greater than had been believed. These species are here reported in Asia for the first time.

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References

Agardh, C.A. (1830) *Conspectus Criticus Diatomacearum. Part 1*. Litteris Berlingianis, Lund, 16 pp.

Brébisson, A. (1838) *Considérations sur les Diatomées, et essai d'une classification des genres et des espèces appartenant a cette famille.*

Brée, pp. 1–20.

Burliga, A.L., Kociolek, J.P., Salomoni, S.E. & Figueiredo, D. (2013) A new genus and species in the diatom family Eunotiaceae Kützing (Bacillariophyceae) from the Amazonian hydrographic region, Brazil. *Phytotaxa* 79 (2): 47–57. https://doi.org/10.11646/phytotaxa.79.2.1

Cantonati, M. & Lange-Bertalot, H (2010) Diatom biodiversity of springs in the Berchtesgaden National Park (north-eastern Alps, Germany), with the ecological and morphological characterization of two species new to science. *Diatom Research* 25 (2): 251–280. https://doi.org/10.1080/0269249X.2010.9705849

Chen, Y., Lei, B., Luo, C.D., Wang, H.Y., Ma, D. & Liu, L. (2013) Study on soil organic matter and predict its storage of abies faxoniana forest in Mugecuo, Kangding. *Journal of Soil and Water Conservation* 27 (4): 252–257.

Cleve-Euler, A. (1953) Die Diatomeen von Schweden und Finnland. Part III. *Monoraphideae*, *Biraphideae* 1. *Kongliga Svenska Vetenskaps-Akademiens Handligar* Ser. 4, 4: 1–255.

Ehrenberg, C.G. (1832) Ьber die Entwickelung und Lebensdauer der Infusionsthiere; nebst ferneren Beitrдgen zu einer Vergleichung ihrer organischen Systeme. *Abhandlungen der Kцniglichen Akademie Wissenschaften zu Berlin, Physikalische Klasse* 1831: 1–154.

Ehrenberg, C.G. (1837) Über ein aus fossilen Infusorien bestehendes, 1832 zu Brot verbacknes Bergmehl von den Grenzen Lapplands in Schweden. *Bericht über die zur Bekanntmachung geeigneten Verhandlungen der Kònigl. Preuss. Akademie der Wissenschaften zu Berlin* 1837: 43–45.

Ehrenberg, C.G. (1843) Mittheilungen über 2 neue asiatische Lager fossiler Infusorien-Erden aus dem russischen Trans-Kaukasien (Grusien) und Sibirien. *Bericht über die zur Bekanntmachung geeigneten Verhandlungen der Königlich-Preussischen Akademie der Wissenschaften zu Berlin* 1843: 43–49.

Ehrenberg, C.G. (1843) Verbreitung und Einfluss des mikroskopischen Lebens in Süd-und Nord-Amerika. *Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin* 1841: 291–466.

Furey, P.C., Lowe, R.L. & Johansen, J.R. (2011) *Eunotia* Ehrenberg of the Great Smoky Mountains National Park, U.S.A. *Bibliotheca Diatomologica* 56: 1–134.

Furey, P.C., Lowe, R.L. & Johansen, J.R. (2009) Teratology in *Eunotia* taxa in the Great Smoky Mountains National park and description of *Eunotia* macroglossa sp. nov. *Diatom Research* 24 (2): 273–290. https://doi.org/10.1080/0269249X.2009.9705802

Gasse, F. (1986) East african diatoms: taxonomy, ecological distribution. *Bibliotheca Diatomologica* 11: 1–201.

Hartley, B. (1996) *An Atlas of British Diatoms.* Biopress Ltd, Bristol, pp. 1–601.

Hassall, A.H. (1845) *A history of the British freshwater algae, including descriptions of the Desmideae and Diatomaceae. With upwards of one hundred plates, illustrating the various species. Vol. I.* London, Edinburgh, Paris & Leipzig: S. Highley, H. Baillière; Sunderland & Knox; J.B. Baillière; T.O. Weigel, pp. [i]–viii, [i]–462.

Hustedt, F. (1930) Bacillariophyta (diatomeae). *Die Susswasser-Flora Mitteleuropas* 10: 1–466.

Hustedt, F. (1937–1939) Systematische und ökologische Untersuchungen über die DiatomeenFlora von Java, Bali und Sumatra. *Archiv für Hydrobiologie, Supplement* Bd. 15: u.16.

Kanitz, A. (1880) Plantas Romaniae hucusque cognitas. *Magyar Novenytani Lapok* 5: 151–165, 261–268.

Kobayasi, H., Ando, K. & Nagumo, T. (1981) On some endemic species of the genus *Eunotia* in Japan. *In:* Ross, R. (Ed.) *Proceedings of the Sixth Symposium on Recent and Fossil Diatoms, Budapest, September 1–5, 1980, Taxonomy-Morphology-Ecology- Biology.* Koeltz Publishing, Koenigstein, pp. 93–114.

Kociolek, J.P., You, Q.M., Stepanek, J., Lowe, R.L. & Wang, Q.X. (2016) A new *Eunotia* (Bacillariophyta: Eunotiales) species from Karst formations of southern China. *Phytotaxa* 265 (3): 285–293. https://doi.org/10.11646/phytotaxa.265.3.10

Krammer, K. & Lange-Bertalot, H. (2004) Bacillariophyceae. 3: Centrales, Fragilariaceae, Eunotiaceae. *In: Süßwasserflora von Mitteleuropa. Band 2/3*. VRG Gustav Fisher Verlag, Jena, pp. 1–599.

Kulikovskiy, M., Lange-Bertalot, H., Genkal, S. & Witkowski, A. (2010) *Eunotia* (Bacillariophyta) in the Holarctic: new species from the Russian Arctic. *Polish Botanical Journal* 55 (1): 93–106.

Kwandrans, J. (1993) Diatom communities of acidic mountain streams in Poland. *In:* Twelfth International Diatom Symposium. *Hydrobiologia* 269/270: 335–342. https://doi.org/10.1007/978-94-017-3622-0_35

Lange-Bertalot, H. (1993) 85 neue Taxa und über 100 weitere neu definierte Taxa ergänzend zur Süsswasserflora von Mitteleuropa, Vol. 2/1–4. *Bibliotheca Diatomologica* 27: 1–164

Lange-Bertalot, H. & Genkal, S.I. (1999) Diatoms from Siberia I. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica* 6: 1–292.

Lange-Bertalot, H. & Metzeltin, D. (1996) Indicators of Oligotrophy. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica*

2: 1–390.

Lange-Bertalot, H., Witkowski, M. & Tagliaventi, N. (2011) *Diatoms of Europe: Diatoms of the European inland waters and comparable habitats. Vol. 6: Eunotia and some related genera.* ARG Gantner Verlag KG, Ruggell, pp. 1–747.

Liu, Y., Wang, Q.X., & Fu, C.X. (2011) Taxonomy and distribution of diatoms in the genus *Eunotia* from the Da'erbin Lake and Surrounding Bogs in the Great Xing'an Mountains, China. *Nova Hedwigia* 92 (1–2): 205–232. https://doi.org/10.1127/0029-5035/2011/0092-0205

Liu, D., Jia, S.Y., Jiang, Y. & Li, X. (1996) Hot mineral water features and genetic model of Mugeuo Scenic Spot, Kangding. *Journal of Railway Engineering* 2: 155–162.

Lyngbye, H.C. (1819) *Tentamen hydrophytologiae danicae continens omnia hydrophyta cryptogama Daniae, Holsatiae, Faeroae, Islandiae, Groenlandiae hucusque cognita, systematice disposita, descripta et iconibus illustrata, adjectis simul speciebus norvegicis*. Copenhague, 248 pp.

Metzeltin, D. & Lange-Bertalot, H. (1998) Tropical Diatoms of South America I. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica* 5: 1–695.

Metzeltin, D. & Lange-Bertalot, H. (2002) Diatoms from the "Island Continent" Madagascar. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica* 11: 1–286.

Metzeltin, D., Lange-Bertalot, H. & Garcia-Rodriguez, F. (2005) Diatoms of Uruguay. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica* 15: 1–736.

Metzeltin, D. & Lange-Bertalot, H. (2007) Tropical diatoms of South America II. Special remarks on biogeography disjunction. *Iconographia Diatomologica* 18: 1–877.

Metzeltin, D. & Witkowski, A. (1996) Diatomeen der Bären-Insel. Süsswasser- und marine Arten. *In*: Lange-Bertalot, H. (Ed.) Annotated Diatom Micrographs. Vol. 4. Taxonomy. *Iconographia Diatomologica* 4: 1–217. [Koeltz Scientific Books, Königstein, Germany]

Migula, W. (1905) *Kryptogamen-Flora von Deutschland, Deutsch-Österreich und der Schweiz. Band II. Algen. 1. Teil. Cyanophyceae, Diatomaceae, Chlorophyceae.* H. Bergmühler, Berlin, pp. 1–208.

Novitski, L., Kociolek, J.P. & Fourtanier, E. (2005) Preliminary light and scanning electron microscope observations of marine fossil *Eunotia* species with comments on the evolution of the genus *Eunotia*. *Diatom Research* 20: 137–143. https://doi.org/10.1080/0269249X.2005.9705623

Patrick, R. & Reimer, C.W. (1966) The diatoms of the United States. Vol. 1. *Monographs of the Academy of Natural Sciences of Philadelphia* 1 (13): 1–688.

Pavlov, A. & Levkov, Z. (2013) Diversity and distribution of taxa in the genus *Eunotia* Ehrenberg (Bacillariophyta) in Macedonia. *Phytotaxa* 86 (1): 1–117. https://doi.org/10.11646/phytotaxa.86.1.1

Qi, Y.Z. & Li, J.Y. (2004) *Fora Algarum Sinicarum Aquae Dulcis, Tomus 10, Bacillariophyta-Pennatae.* Science Press, Beijing, pp. 1–130.

Rabenhorst, L. (1864) *Flora europaea algarum aquae dulcis et submarinae. Sectio I. Algas diatomaceas complectens, cum figuris generum omnium xylographice impressis.* Kummer, Leipzig, 359 pp.

Round, F.E., Crawford, R.M. & Mann, D.G. (1990) *The diatoms. Biology & morphology of the genera.* Cambridge Univ. Press, pp. 1–747.

Rumrich, U., Lange-Bertalot, H. & Rumrich, M. (2000) Diatoms of the Andes. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica* 9: 1–673.

Skvortzow, B. (1930) Alpine diatoms from Fukien Province, South China. *The Philippine Journal of Science* 41: 39–49.

Skvortzow, B. (1938) Diatoms From A Mountain Bog, Kaolingtze,Pin-Chiang-Sheng Province. *The Philippine Journal of Science* 66: 343–362.

Siver, P.A., Hamilton, P.B., Stachura-Suchoples, K. & Kociolek, J.P. (2005) Diatoms of North America: The Freshwater Flora of Cape Code, Massachus&ts, U.S.A. Koeltz Scientific Books, Koenigstein. *Iconographia Diatomologica* 14: 1–463.

Van Heurck, H. (1881) *Synopsis des Diatomées de Belgique Atlas.* pls. XXXI–LXXVII.

Veen, A., Hof, C.H.J., Kouwets, F.A.C. & Berkhout, T. (2015) *Taxa Watermanagement the Netherlands (TWN) Rijkswaterstaat Waterdienst, Informatiehuis Water.*

Werum, M. & Lange-Bertalot, H. (2004) Diatoms in Springs. Koeltz Scientific Books, Koenigstein. Icon. Diatom.13: 1–479.

Wetzel, C.E., Lange-Bertalot, H., Morales, E.A., Bicudo, D.D.C., Hoffmann, L. & Ector, L. (2012) *Bicudoa amazonica* gen. nov. et sp. nov. (Bacillariophyta) a new freshwater diatom from the Amazon basin with a complete raphe loss in the Eunotioid lineage. *Phytotaxa* 75 (1): 1–18. https://doi.org/10.11646/phytotaxa.75.1.1

Yang, JG. (1995) A new species of the *Eunotia* genus from Anhui Province. *Journal of the Chinese Academy of Sciences* 33 (2): 206–207.

You, Q.M., Kociolek, J.P., Cai, M.J., Lowe, R.L., Liu, Y. & Wang, Q.X. (2017) Morphology and ultrastructure of Sellaphora constrictum sp. nov. (Bacillariophyta), a new diatom from southern China. *Phytotaxa* 327 (3): 261–268. https://doi.org/10.11646/phytotaxa.327.3.5

Zhang, ZA. & Qi, YZ. (1993) New species and new record taxa of the *Eunotia* genus from China (2). *Journal of Jinan University: Natural Science and Medicine Edition* 1: 80–83.

Zhu, H.Z. & Chen, J.Y. (2000) *Bacillariophyta of the Xizang Plateau.* Science Press, Beijing, pp. 1–353.