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ABSTRACT
Seven species from the genera *Kobayasiella* (*K. madumensis* Jørgensen, *K. micropunctata* Germain, *K. parasubtilissima* Kobayasi & Nagumo, *K. pseudostauron* Lange-Bertalot, *K. subtilissima* P.T.Cleve), *Adlafia* (*A. bryophila* Petersen) and *Nupela* (*N. tenuicephala* Hustedt) from oligotrophic lakes of the subarctic boreal zone in Tursujuq National Park in Nunavik (northern Québec, Canada), were studied by light and scanning electron microscopy and linked with environmental conditions. In addition, four new species, *Kobayasiella tursujuqensis* sp. nov., *Adlafia umiujaqensis* sp. nov., *Adlafia ossiformis* sp. nov., and *Sellaphora vincentiana* sp. nov., were observed and described. The new species are similar in light microscope observations to other species in their associated genera, but can be identified based on independent character traits under a combined LM and SEM analysis. Morphological structures of particular interest include valve outline, position of the central and terminal raphe fissures, orientation of the striae, and the structural formation of the areolae within the striae. Due to low taxon abundances, distribution patterns of these species in the park were difficult to identify. *Kobayasiella parasubtilissima*, *K. subtilissima*, *K. tursujuqensis* sp. nov. and *N. tenuicephala* were associated with acidic conditions while *K. pseudostauron*, *A. bryophila* and *S. vincentiana* sp. nov. were found in circumneutral waters. A better knowledge of small naviculoid species is necessary to document the circumpolar biogeography and ecology of diatoms for a better understanding of the dynamic of those organisms in changing environmental conditions within the context of rapid climate change in northern regions.

KEY WORDS
Diatoms,
naviculoids,
Nunavik,
water chemistry,
new species.

RÉSUMÉ

Petites espèces naviculoïdes de Kobayasiella *Lange-Bertalot,* Adlafia *Moser, Lange-Bertalot & Metzeltin,* Nupela *Vyverman & Compère and* Sellaphora *Mereschowsky du parc national Tursujuq, baie d'Hudson, Nunavik, Québec.*

Sept espèces des genres *Kobayasiella* (*K. madumensis* Jørgensen, *K. micropunctata* Germain, *K. parasubtilissima* Kobayasi & Nagumo, *K. pseudostauron* Lange-Bertalot, *K. subtilissima* P.T.Cleve), *Adlafia* (*A. bryophila* Petersen) et *Nupela* (*N. tenuicephala* Hustedt) provenant de lacs oligotrophes de la zone boréale subarctique du parc Tursujuq au Nunavik (nord du Québec, Canada), ont été étudiées par microscopes optique (LM) et électronique à balayage (SEM), et les conditions environnementales de leur lieu de vie ont été caractérisées. Quatre nouvelles espèces, *Kobayasiella tursujuqensis* sp. nov., *Adlafia umiujaqensis* sp. nov., *Adlafia ossiformis* sp. nov., et *Sellaphora vincentiana* sp. nov., ont été observées et décrites. Bien que similaires à d'autres espèces de leurs genres par observations LM, elles peuvent être différenciées sur la base de traits de caractère indépendants, en combinant des analyses LM et SEM. Les structures morphologiques présentant un intérêt particulier comprennent le contour de la valve, la position des fissures du raphé central et terminal, l'orientation des stries et la formation structurelle des aréoles dans les stries. En raison de la faible abondance des taxons, les schémas de distribution de ces espèces dans le parc ont été difficiles à identifier. *Kobayasiella parasubtilissima*, *K. subtilissima*, *K. tursujuqensis* sp. nov. et *N. tenuicephala* sont associées aux conditions acides tandis que *K. pseudostauron*, *A. bryophila* et *S. vincentiana* sp. nov. sont associées aux eaux circumneutres. Une meilleure connaissance des espèces naviculoides de petites tailles est nécessaire pour documenter la biogéographie et l'écologie des diatomées afin de mieux comprendre la dynamique de ces organismes dans des conditions environnementales fluctuantes dans un contexte de changement climatique rapide dans les régions boréales.

MOTS CLÉS
Diatomées, naviculoïdes, Nunavik, composition de l'eau, espèces nouvelles.

INTRODUCTION

The diatom genera *Kobayasiella* Lange-Bertalot (Lange-Bertalot & Genkal 1999), *Adlafia* Moser, Lange-Bertalot & Metzeltin (Moser *et al*. 1998), *Nupela* Vyverman & Compère (1991) and *Sellaphora* Mereschkowsky (1902) contain small species which are often difficult to identify using conventional light microscopy (LM). The inability to distinguish morphological characters (e.g. areolae) and fine details of shape hinder complete identifications. With increased global environmental change there is a need for better species identifications when conducting and modelling water quality assessments. Fine detailed taxonomic identifications are becoming the new standard, with the need for better documentation of phenotypic expression. At present, there is a poor understanding of phenotypic and genotypic expression in microbes, such as diatoms, which adds to the difficulty in identifying and differentiating species or even functional taxonomic groups. The search for identifiable features, or key synapomorphic characters, is required to understand the precise levels of species diversity for reliable environmental assessments. The objective of this study is to identify key characteristics of small problematic species with naviculoid morphologies from freshwaters in the Canadian Subarctic. Species representing four genera created from taxa within the old section *Navicula subtilissima* Cleve (Hustedt 1966) are examined from Tursujuq National Park, Nunavik, Québec, Canada, with four species new to science identified.

The genus *Kobayasiella* is characterized by frustules that are lightly to moderately silicified, and linear-elliptic to linear-lanceolate in shape (Glushchenko *et al*. 2020). The raphe is straight and filiform which is characteristic of many naviculoid genera. One original feature is the presence of a kink-like irregularity or umbilicus closer to the valve apices along the otherwise straight raphe fissure. This umbilicus is often called a notch or a kink (Vanhoutte *et al*. 2004; Buczkó & Wojtal 2007). The proximal raphe ends are straight or elongated teardrop-shaped, while the terminal raphe fissures are hooked on the valve face, not continuing onto the mantle (Kobayasi & Nagumo 1988; Le Cohu & Azémar 2010; Glushchenko *et al*. 2020). There is a narrow marginal hyaline region at the valve face mantle junction. Striae are alveoli-like apertures with recessed pores which are arranged radially at the mid-valve changing to convergent at the Voigt fault and then extending to the apices. The alveoli-like apertures are *Pinnularia*-like, with fine multiseriate pores that extend across the external valve face. When present, the apertures are circular to elliptic and covered by a multiseriate thin perforated hymen on the valve face. Internally, a narrow raised sternum serves as a structural support for the valve; the raphe has straight or T-shaped proximal ends and a small raised helictoglossa at the distal end (Glushchenko *et al*. 2020).

Species within the genus *Adlafia* are relatively small, typically less than 25 µm in length. Like *Kobayasiella*, the raphe is linear to weakly curved. *Adlafia* is primarily distinguished from *Kobayasiella* by the absence of an umbilicus and the formation of the terminal raphe fissure on the mantle. The external proximal raphe ends are slightly enlarged to teardrop-shaped and weakly bent to the opposite side from the terminal raphe fissure, while the terminal raphe fissures are bent in the same direction and extend to the mantle. One of the distinctive features of this genus is the shape of the areolae. They are large and round and covered externally by a multiseriate hymen and a silica layer at the outer periphery of each areola. Internally, the proximal ends are bent in the same direction and the terminal raphe fissures terminate in a small elevated helictoglossa.

Like *Adlafia*, species of the genus *Nupela* are typically small, less than 20 µm in length. At present, species in *Nupela* can be isovalvar, or heterovalvar with different raphe systems. The raphe can be fully developed or missing on one or two valves, or one valve can have a shortened raphe (Siver *et al.* 2007). The areolae are a distinctive feature of this genus, elliptical in outline and externally covered with a hymen.

Sellaphora is a large genus with high morphological diversity (Mann *et al.* 2008). The presence of the hymen that covers the valves can further obscure the details and distinctive features of the small areolae, making their detection and identification more challenging with LM. Externally, the raphe has fissures that are slightly deflected at the centre and curved at both ends. Internally, the central raphe ends are deflected. The terminal raphe fissures terminate in a long helictoglossa (Mann 1989). At present, *Sellaphora* is genetically associated with *Eolimna* Lange-Bertalot & Schiller, while *Adlafia* is distant in the phylogenetic tree and aligned with *Geissleria* Lange-Bertalot & Metzeltin and *Placoneis* Mereschkowsky (Nakov *et al.* 2019). In contrast, *Nupela* and *Kobayasiella* have a chloroplast genetic affinity to *Pinnularia* Ehrenb. (Pinnulariaceae) and, to a lesser extent, to *Stauroneis* Ehrenb. (Stauroneidaceae) (Nakov *et al.* 2019).

Currently, 36 *Kobayasiella* species are referenced in the literature of which 32 have been accepted taxonomically; 37 *Adlafia* species are referenced with 34 accepted taxonomically. A further 87 *Nupela* and 260 *Sellaphora* species are also recognized (Fallu *et al.* 2000; Guiry & Guiry 2018). Fallu *et al.* (2000) identified eight small *Navicula* (naviculoid) species and one *Nupela* species along a latitudinal transect in northern Québec which are included in the species presented in this article. Ponader *et al.* (2002), Saulnier-Talbot & Pienitz (2002) and Hobbs *et al.* (2010) have also documented diatom biogeographic distributions in northern Québec including three of the taxa examined in this study: *Kobayasiella subtilissima* (Cleve) Lange-Bertalot (as *Navicula subtilissima*), *Kobayasiella micropunctata* (Germain) Lange-Bertalot (as *Navicula micropunctata* (Germain) Kobayasi & Nagumo), and *Adlafia bryophila* (J.B.Petersen) Lange-Bertalot (as *Navicula bryophila* J.B.Petersen). The internal structures of these species can now be thoroughly analyzed with electron microscopy. The objective of this study is to document the presence and biodiversity of *Kobayasiella*, *Adlafia*, *Sellaphora* and *Nupela* species from Tursujuq National Park in Nunavik (northern Québec), Canada. Detailed LM and SEM-based observations reveal four populations that are distinct species and described here as new to science.

MATERIAL AND METHODS

Tursujuq National Park is the largest national park in eastern continental North America. Located in the Nord-du-Québec region, it covers an area of 26 106 km², from 55°30' to 57°00' latitude N and from 72°00' to 77°00' longitude W. In its western sector, the Hudsonian cuesta successions are under the influence of Hudson Bay's climate with surface deposits of marine and fluvioglacial origin, sandstone and basalt bedrock, and an Arctic subhumid vegetation. To the east, the Hudson Highlands are traversed by numerous streams and lakes, the surface deposits are of glacial origin, the bedrock is composed of gneiss and granite and the vegetation is boreal subhumid. The park has three major lake systems: Lake Tasiujaq (previously known as Lac Guillaume-Delisle or Richmond Gulf), Lake des Loups Marins and Lake Wiyâshâkimi (previously called Lac-à-l'Eau-Claire or Clearwater Lake), with an additional *c.* 1500 smaller lakes. Forty-seven lakes were sampled throughout this highly diverse territory for water quality and bioindicator surveys (Fig. 1).

Sampling was done in two stages. First, in August 2015, 35 lakes were sampled in the Lakes Wiyâshâkimi and Umiujaq sectors. A second series of 14 lakes was sampled in August 2016 between the first two sectors. Table 1 summarizes the main characteristics of the sampling sites. A surface sediment and water sample were collected for each of the 47 lakes with a Mini-Glew corer (Glew 1991), whereby the upper centimetre of each core, representing *c.* three to five years of accumulation, was sampled in the field into sterile WhirlPak bags. Limnological measurements included temperature, pH, conductivity, and dissolved oxygen (DO) taken with a YSI 6000 QS multiparameter sonde just below the water surface.

In the laboratory, water chemistry analyses were performed using standard methods at Environment Canada's National Laboratory for Environmental Testing at the Canada Centre for Inland Waters (Environment Canada, 1994) to analyse the concentrations of dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP). Total phosphorus (TP), total nitrogen (TN), nitrite/nitrate, major ions and alkalinity. The diatom samples were oxidized with hydrogen peroxide to remove organic matter (Pienitz *et al.* 1995; Hay *et al.* 1997). After oxidation, they were rinsed three times with deionized water and the resultant slurries were spread on coverslips and left to dry in a dust-free environment. Finally, the coverslips were mounted on microscope slides with Naphrax mounting medium. Light microscope observations and photography were conducted using a Zeiss Axio Imager A2 microscope equipped with a 100× oil immersion objective (Plan-APOCHROMAT 100× 1.4 NA DIC) and an AxioCam MRm digital camera. Photographic plates were prepared using the softwares GIMP and Inkscape. Species optima were calculated with RStudio version 2.1-7 (RStudio Team 2022) and the op_calculated function of the optimos.prime package, according to the method of Potapova & Charles (2003).

For SEM analysis, a subsample of oxidized material was diluted with deionized water and dried on a small square

Table 1. — DOC optima determined for the 11 taxa examined in this study and also found in Fallu *et al.* (2000).

Species name	Fallu *et al*. (2000) Optimum (Opt. ± tol.; mg/L)	Tursujuq Optimum (mg/L)
Kobayasiella parasubtilissima Kobayasi & Nagumo	7.03 ± 1.751	6.90
Kobayasiella madumensis Jørgensen	–	4.08
Kobayasiella subtilissima P.T.Cleve	4.14 ± 1.96	5.47
Kobayasiella tursujuqensis sp. nov.	9.56 ± 1.21	6.38
Kobayasiella pseudostauron Lange-Bertalot	–	3.80
Kobayasiella micropunctata Germain	7.03 ± 1.75	3.68
Adlafia bryophila Petersen	6.29 ± 1.58	3.72
Adlafia umiujaqensis sp. nov.	5.83 ± 1.47	7.25
Adlafia ossiformis sp. nov.	6.74 ± 1.64	–
Sellaphora vincentiana sp. nov.	9.7 ± 1.39	7.11
Nupela tenuicephala Hustedt	9.30 ± 1.68	4.91

Table 2. — Correspondence between the species of this article and those of Fallu *et al.* (2000).

Species name	Name in Fallu *et al*. (2000)
Kobayasiella parasubtilissima Kobayasi & Nagumo	*Navicula parasubtilissima*
Kobayasiella madumensis Jørgensen	Not found
Kobayasiella subtilissima P.T.Cleve	*Navicula subtilissima*
Kobayasiella tursujuqensis sp. nov.	cf. *Navicula difficilima*
Kobayasiella pseudostauron Lange-Bertalot	Not found
Kobayasiella micropunctata Germain	*Navicula micropunctata*
Adlafia bryophila Petersen	*Navicula bryophila*
Adlafia umiujaqensis sp. nov.	*Navicula digitulus*
Adlafia ossiformis sp. nov.	*Navicula ventralis*
Sellaphora vincentiana sp. nov.	*Navicula gerlofii*
Nupela tenuicephala Hustedt	*Nupela tenuicephala*

of aluminium foil (2 cm^2). The aluminium foil was then attached to an aluminium stub using double sided carbon tape and further secured by wrapping the edges of the foil around the edge of the stub. The stubs were sputter-coated with a platinum layer of approximately 10 nm using a Denton Desk II sputter coater (Denton Vacuum, Moorestown, NJ, United States). Samples were analysed using an APREO (FEI, Hillsboro, Oregon, United States) ultra-high-resolution analytical field emission scanning electron microscope with backscatter (T1, T3), and secondary electrons (EDS) imaging using the FEI optimum setting. Operating voltage was set to 5 kV, spot size 7 and working distances from 1.5-10 mm. Slides and stubs analysed in this study are stored at the Canadian Museum of Nature, Canada (CANA[129448-129555]). SEM plates were prepared using Adobe Photoshop 7.0.

The terminology used follows Ross *et al.* (1979) for the general silica frustule and areola structure, and Cox & Ross (1981) for stria structure. The term sternum refers to the primary and secondary silica ribs associated with initial valve formation, while axial area represents the hyaline region between the raphe and the striae. The principal studies used for taxonomic comparisons included: Meister (1935); Bourrelly & Manguin (1952); Cholnoky & Schindler (1953); Germain (1981); Kobayasi & Nagumo (1988); Lange-Bertalot & Metzeltin (1996); Lange-Bertalot (1999); Lange-Bertalot & Genkal (1999); Camburn & Charles (2000); Fallu *et al.* (2000); Siver *et al.* (2005); Metzeltin & Lange-Bertalot (2007); Lavoie (2008); Siver & Hamilton (2011); Bahls (2013); Bahls *et al.* (2018).

For typification of the new species, we chose a marked single specimen on the slide as the holotype following article 8.2 of the International Code for Botanical Nomenclature (Turland *et al.* 2018).

RESULTS

Family Naviculaceae Kützing
Genus *Kobayasiella* Lange-Bertalot

Kobayasiella parasubtilissima
(Kobayasi & Nagumo) Lange-Bertalot
(Figs 2A-P; 4A-H)

Iconographia Diatomologica 6: 268 (Lange-Bertalot 1999). — *Navicula parasubtilissima* Kobayasi & Nagumo, *The Botanical Magazine, Tokyo* 101 (1063): 245 (Kobayasi & Nagumo 1988).

Ecology and distribution. — *Kobayasiella parasubtilissima* was found in ten lakes. A rare species, with a mean relative abundance of 0.2% and a maximum of 5.5% in Lake 16-H. Although rare, this species was more abundant in acidic conditions (Appendix 3) with a pH optimum of 5.7 and a relatively high DOC optimum of 6.9 mg/L (Appendix 2). Camburn & Charles (2000), Fallu *et al.* (2000), and Siver & Hamilton (2011) all reported this taxon from low alkalinity, low pH waters across eastern North America. Siver *et al.* (2005) and Bahls (2012b) also observed this taxon with a mixed population of more than one species from western North America. *Kobayasiella parasubtilissima* has also been reported from Europe, suggesting that this is a globally distributed species.

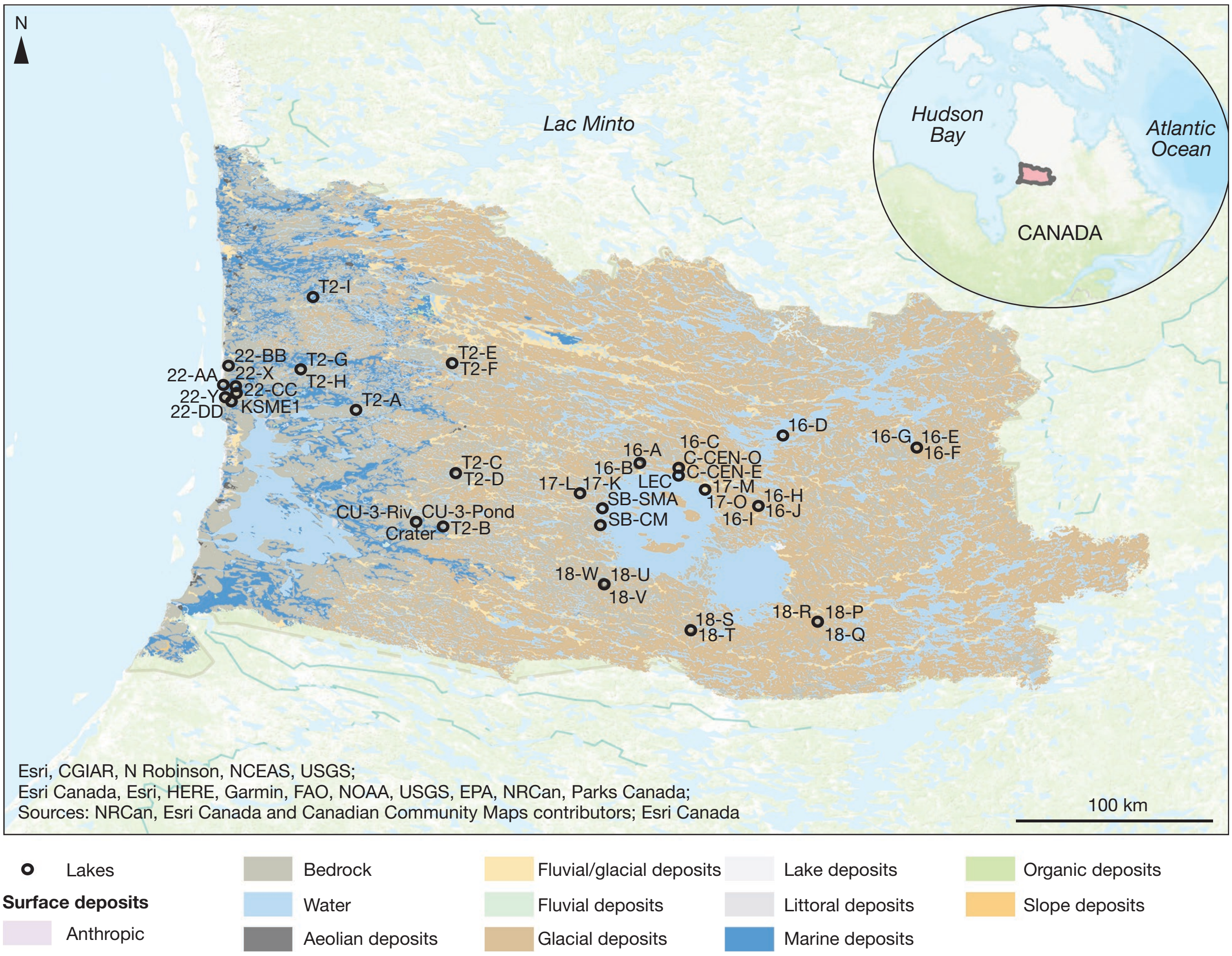

Fig. 1. — Lake sampling locations and surface deposits in Tursujuq National Park. **Insert** shows the position of Tursujuq Park in Nunavik, Québec, eastern North America.

Description

The frustules exhibit a rectangular and narrow shape in girdle view. The valves are narrow, ranging from linear to linear-lanceolate, with capitate ends. Based on a sample size of 21, the valve dimensions vary, with a length ranging from 27 to 33.5 µm and a width ranging from 3.5 to 5 µm. The length-to-width ratio is 6.5 to 7.0. The stria density ranges from 45 to 50 in 10 µm. The axial area is linear to lanceolate and narrow. The central area is weakly linear-elliptic, exhibiting 7-8 marginal striae of varying lengths. The valve face is flat. The raphe is linear, with a distinct kink-like irregularity occurring halfway between the mid-valve and apex (Fig. 4A). The central raphe fissures are widely spaced, linearly expanded, and rounded. The terminal raphe fissures are weakly curved on the valve face, opening with an external linear to funnel-like groove (Fig. 4A, G). Internally, the raphe is situated on a thickened sternum, appearing straight without a kink-like regularity. The proximal raphe fissures are T-shaped depressions, while the terminal fissures end on elongated helictoglossae, isolated from the apex mantle (Fig. 4F, E, H). The striae exhibit a radial pattern at the mid-valve and become strongly convergent towards the apices (Fig. 4B). From the mid-valve to the Voigt fault, the individual striae become straight to bent, while from the Voigt fault to the apex, they change from bent to straight. The striae possess 4-6 (sometimes 9) rows of pores. The striae are interrupted by a hyaline valve face/mantle margin along the valve sides and extend uninterrupted around the apices. Distinct Voigt faults can be observed on both the primary and secondary sides of the valve, located at ⅔ of the distance between the mid-valve and apex. The striae are covered with 4-6 (sometimes more) rows of small multiseriate pores. Internally, the multiseriate pores are positioned between thickened virgae. Small silica projections from the virgae may or may not be present. The cingulum features 3-4 open copulae bands, with the copulae exhibiting two linear rows of pores at the pars interior. Additionally, a velum-like cover with 6-8 openings covers the pores. Occasionally, a fringe can be observed at the base of a copula.

Specimens from Tursujuq National Park match specimens from the original publication of Kobayasi & Nagumo (1988) with the characteristic linear narrow valves with capitate ends and a length to width ratio between 6.5 and 7.0. Populations in Tursujuq National Park were at the larger end of the described size range, with slightly wider valves (up to 5 µm)

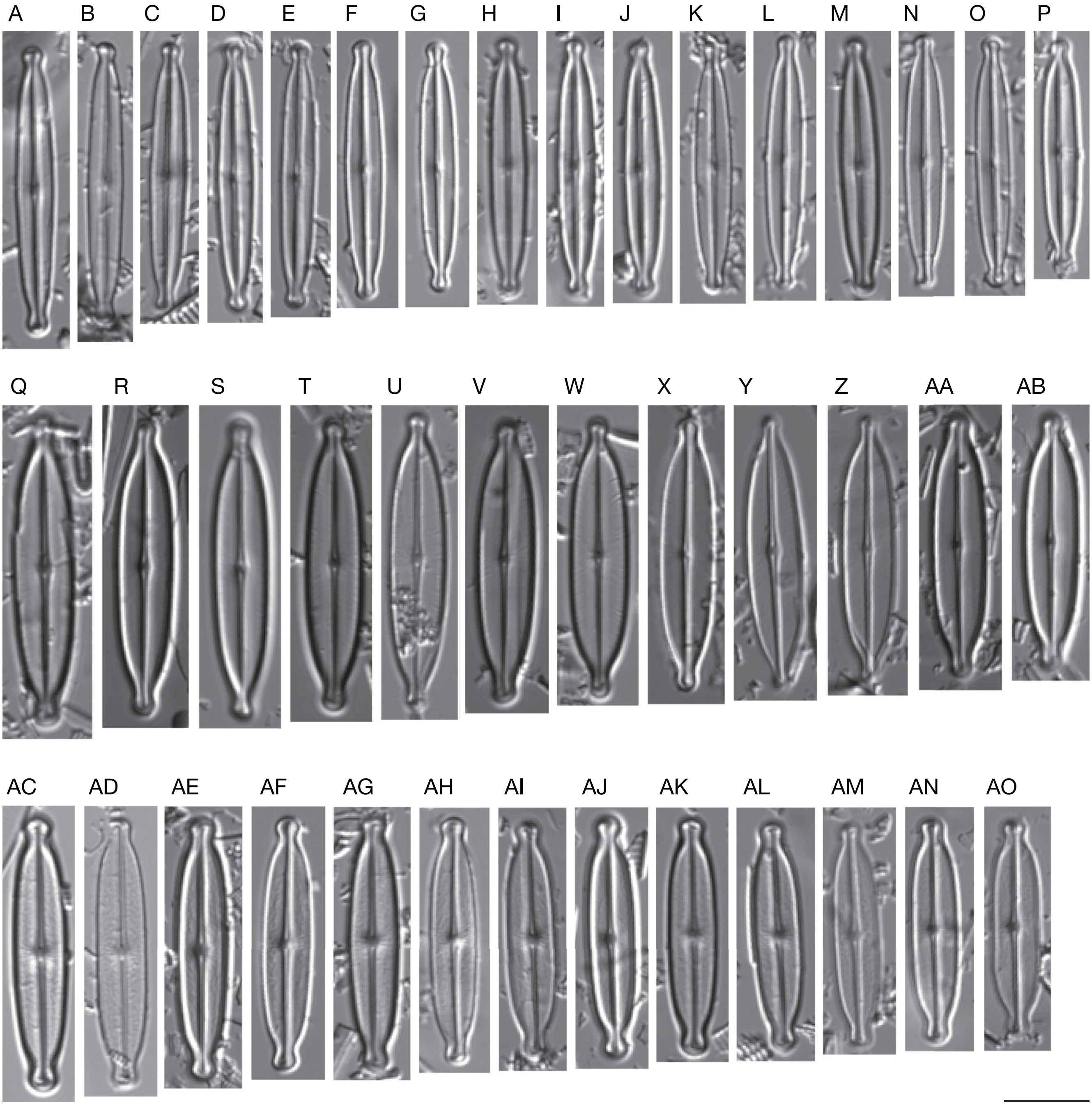

Fig. 2. — Light micrograph diminution series of *Kobayasiella* Lange-Bertalot species: **A**-**P**, *Kobayasiella parasubtilissima* (Kobayasi & Nagumo) Lange-Bertalot; **Q**-**AB**, *Kobayasiella madumensis* (Jørgensen) Lange-Bertalot; **AC**-**AO**, *Kobayasiella subtilissima* (Cleve) Lange-Bertalot. Scale bar: 10 µm.

and a higher stria density (up to 50 in 10 µm) when including irregular smaller striae along the valve margin.

Kobayasiella madumensis (Jørgensen) Lange-Bertalot (Figs 2Q-AB; 5A-G)

Iconographia Diatomologica 6: 267 (Lange-Bertalot 1999). — *Navicula madumensis* Jørgensen, *Det Kongelige Danske Videnskabernes Selskab, Biologiske Shrifter* 5 (2): 60 (Jørgensen 1948). — *Kobayasia madumensis* (Jørgensen) Lange-Bertalot, *Iconographia Diatomologica* 4: 282 (Lange-Bertalot 1996).

Ecology and distribution. — *Kobayasiella madumensis* was found in four lakes in this study, never exceeded 1% relative abundance and had no evident ecological preferences. In North America, Camburn & Charles (2000), Metzeltin & Lange-Bertalot (2007) and Siver & Hamilton (2005) reported this species in low alkaline and low pH lakes from the eastern part of the continent.

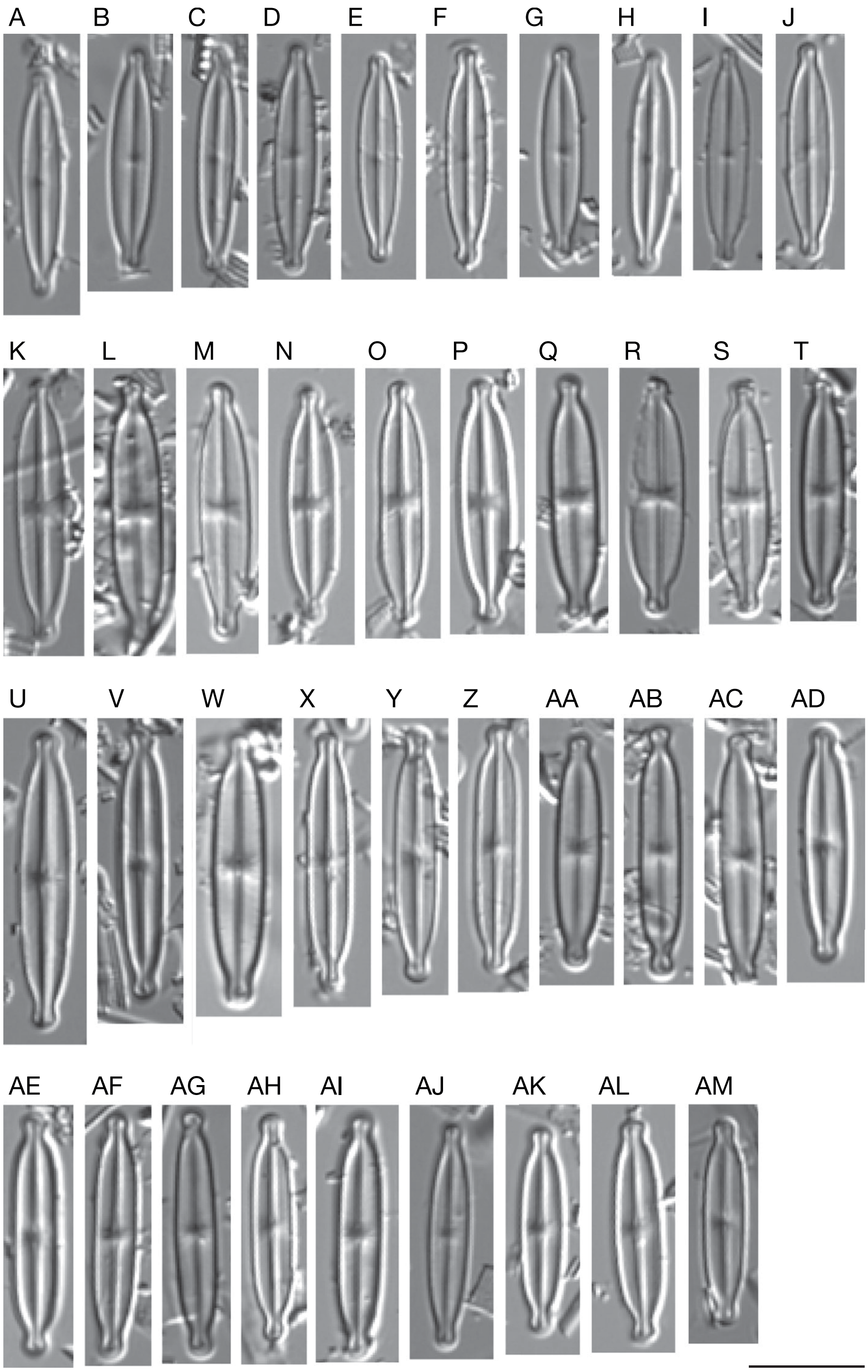

Fig. 3. — Light micrograph diminution series of *Kobayasiella* Lange-Bertalot species: **A**-**J**, *Kobayasiella tursujuqensis* sp. nov.; **K**-**T**. *Kobayasiella pseudostauron* (Lange-Bertalot) Lange-Bertalot. Scale bar: 10 µm.

Description

The frustules have a rectangular and narrow shape in girdle view. The valves are linear-elliptic with more or less capitate protruding ends. Based on a sample size of 15, the valve dimensions range from a length of 29.5 to 37 µm and a width of 5.5 to 7 µm, with the length-to-width ratio from 4.8 to 5.5 µm. The stria density ranges from 37 to 40 in 10 µm. The axial area is lanceolate and narrow, and in LM, it is almost indistinct. The central area is small and apically linear-elliptic, with 9-10 marginal striae of varying lengths aligned between the proximal raphe ends. The external valve face is flat. The raphe is linear, with a kink-like irregularity halfway between the mid-valve and apex. Externally, the central raphe fissures are linearly expanded, with a teardrop-

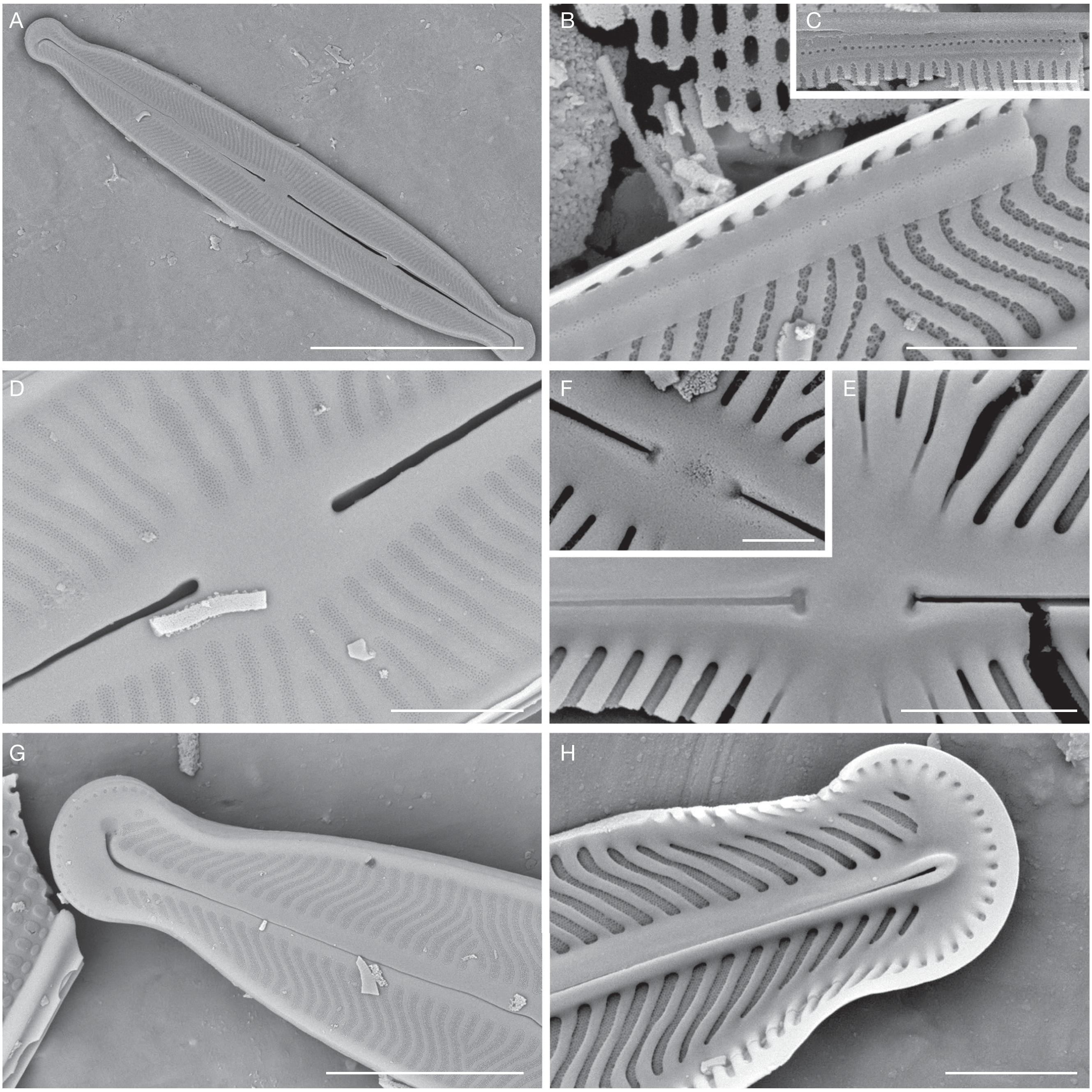

Fig. 4. — SEM images of *Kobayasiella parasubtilissima* (Kobayasi & Nagumo) Lange-Bertalot: **A**, external view of the complete valve; **B**, internal view of the valve areolae recessed between virgae; **C**, section of girdle band showing one row of evident pore and a second row of scattered less evident pores with volae covers; **D**, external view of the axial and central areas showing the multiseriate poroid covers between the virgae; **E**, internal view of the central area showing T-shaped proximal fissures; **F**, central area with a weak central depression; **G**, external view of the valve apex, showing a partially curved proximal fissure opening into a small round surface depression; **H**, internal valve view of the apex. Helictoglossa expanded onto a highline apex. Areolae continuous around the apex. Scale bars: A, 10 µm; B-E, H, 1 µm; F, 600 nm; G, 3 µm.

shaped proximal fissure. The terminal raphe fissures are bent but not hooked, directed towards the secondary side of the valve (Fig. 5F). There is a slightly raised terminal nodule with a terminal axial area. Internally, the raphe is located on a thickened sternum and appears straight, without a kink-like irregularity. The proximal raphe fissures are close together, small, and Y-shaped to T-shaped, with surrounding ridges on the sternum (Fig. 5D, E). The terminal fissures end on raised elongated helictoglossae, isolated from the apex mantle (Fig. 5G). The striae are strongly radiate at the mid-valve and become strongly convergent at the apices. From the mid-valve to the Voigt fault, the individual striae change from straight to bent, and from the Voigt fault to the apex, the striae change from bent to straight. The mantle striae are interrupted by a thick hyaline ridge at the valve face/mantle junction and are not continuous around the apices (Fig. 5F). Distinct Voigt

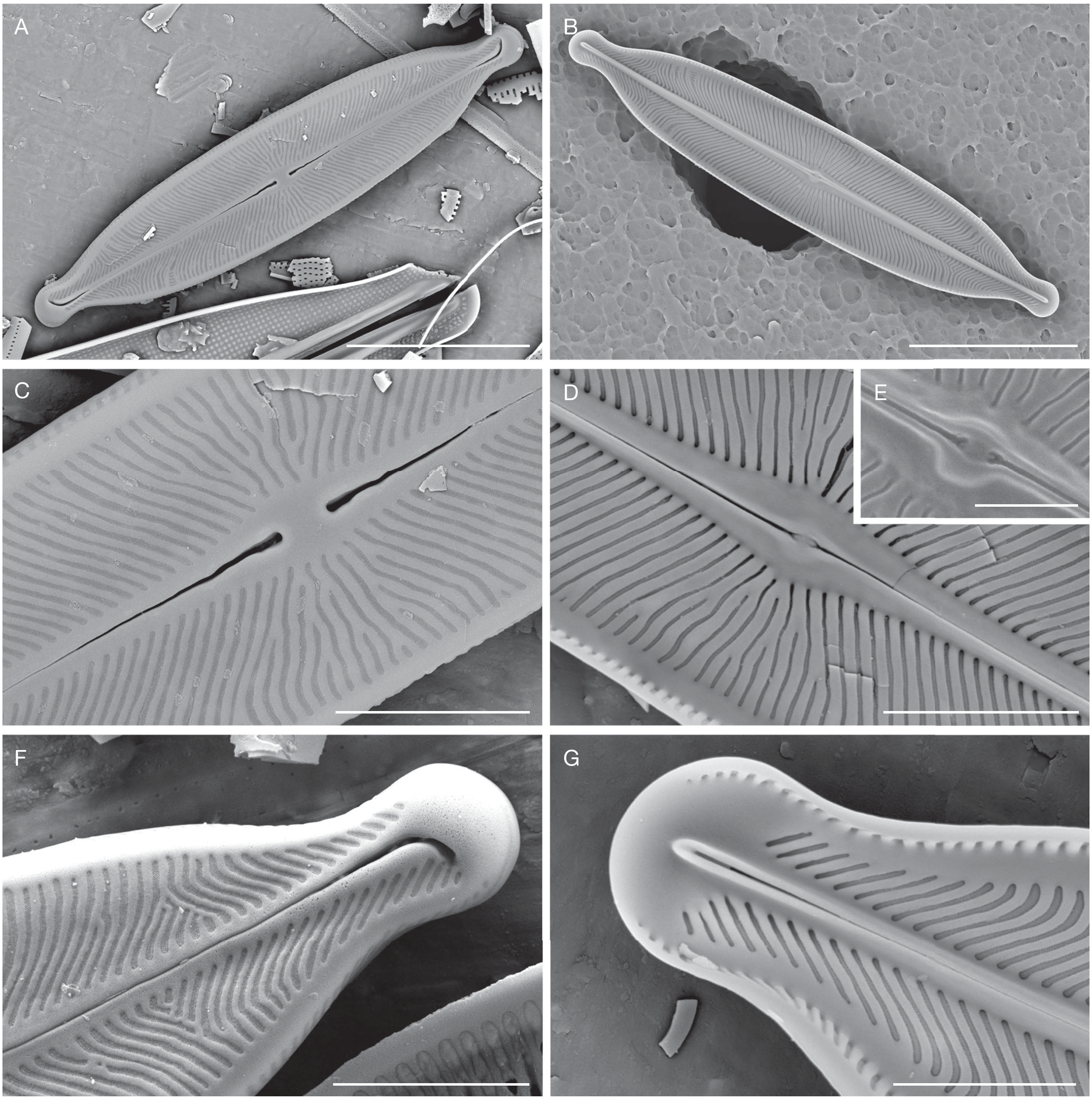

Fig. 5. — SEM images of *Kobayasiella madumensis* (Jørgensen) Lange-Bertalot: **A**, external view of the complete valve; **B**, internal view of the complete valve; **C**, external view of the axial and central areas showing the multiseriate poroid covers between irregular formed virgae; **D**, internal view of the central area showing Y-shaped proximal fissures; **E**, central area with differentially thickened axial ridges; **F**, external view of the valve apex showing an elevated terminal area with a partially curved proximal fissure; **G**, internal valve view of the apex. Helictoglossa expanded onto a highline apex. Areolae interrupted around the apex. Scale bars: A, B, 10 µm; C, D, F, 3 µm; E, 500 nm; G, 2 µm.

faults are present on both the primary and secondary sides of the valve, located at ⅔ of the distance between the mid-valve and apex. Externally, the striae are covered with two rows of small pores. Internally, the biseriate pores are positioned between thickened virgae. Additionally, the striae around the central area are narrow and transapically elongated.

The broader linear-elliptic valve with capitate ends distinguishes this taxon from most *Kobayasiella* species including truly broad taxa such as *K. lange-bertalotii* Metzeltin and *K. krasskei* Metzeltin & Lange-Bertalot. A closely related valve form includes *K. subtilissima sensu* Germain (1981; not *K. subtilissima sensu stricto*), however distinct differences between the Germain specimen and *K. madumensis* are evident with a smaller distance between the central raphe ends and no expanded central area. *Kobayasiella pseudosubtilissima* (Manguin) Lange-Bertalot is similar in outline, but

K. madumensis is distinguished from the former taxon by the small, less curved terminal raphe fissures, the capitate (not rostrate) ends and the higher stria density (37-40 vs 30-32 in 10 µm). Jørgensen first documented a lanceolate taxon with head-shaped extremities (*K. madumensis*) from Madum Sø, Denmark. The original line drawing does not match the current concept of the species, which was established using the examination of type-prep material collected by Jørgensen (HER Nr. 69) (Lange-Bertalot 1996). In this examination Lange-Bertalot reports a linear-elliptic valve similar to that observed in North America. Siver *et al.* (2005) illustrate LM and SEM of *K. madumensis* specimens from Cape Cod (United States) that match specimens from Tursujuq National Park.

Kobayasiella subtilissima (Cleve) Lange-Bertalot (Figs 2AC-AO; 6A-F)

Iconographia Diatomologica 6: 268 (Lange-Bertalot 1999). — *Navicula subtilissima* Cleve, *Actas Societas Pro Fauna et Flora Fennica* 8 (2): 37 (Cleve 1891).

Ecology and distribution. — *Kobayasiella subtilissima* was found in 29 lakes in this study. However, it was present in low relative abundances (mean 1.1%) with a maximum of 10.7% in Lake 18-R. This species was more common in acidic conditions (Appendix 3) with a pH optimum of 6.2 and a relatively low DIC optimum of 0.76 mg/L (Appendix 4). A globally distributed species under consistent environmental conditions.

Description

The frustules are rectangular and narrow in girdle view. The valves exhibit a linear-elliptic to linear-lanceolate shape with subcapitate to capitate ends. Based on a sample size of 22, the valve dimensions range from a length of 25 to 32.5 µm and a width of 5.5 to 6.5 µm. The length-to-width ratio is 4.3 to 5.0.The stria density ranges from 36 to 40 in 10 µm. The external valve face is slightly recessed around the central area. The axial area is linear to lanceolate and narrow. The central area is an expanded axial area, small and round to elliptic, with 6-7 marginal striae oriented between widely spaced proximal raphe fissures. The raphe is linear, with a sharp kink-like irregularity closer to the mid-valve than the apex (Fig. 6A). Externally, the central raphe fissures are linearly expanded with rounded ends. The terminal raphe fissures are bent and deflected on the valve face to one side, opening with an external linear to funnel-like groove (Fig. 6E). Internally, the raphe is located on a thickened sternum and appears straight, without a kink-like irregularity (Fig. 6B). The proximal raphe fissures are T-shaped and located on an elevated central nodule, while the terminal fissures end on elongated helictoglossae, isolated from the apex mantle (Fig. 6D, F). The striae are radiate at the mid-valve and become strongly convergent at the apices. From the mid-valve to the Voigt fault, the striae are flexed, and from the Voigt fault to the apex, the striae change from being flexed to straight. The mantle striae are interrupted by a hyaline ridge at the valve face/mantle junction and are continuous around the apices (Fig. 6E, F). Distinct Voigt faults are present on the secondary side of the valve, located at ⅔ of the distance between the mid-valve and apex (Fig. 6F). The striae are not continuous and are interrupted by thickened vimenes along an apical orientation, except at the apices. The striae are covered with 4-6 rows of small multiseriate pores. Internally, the multiseriate pores are positioned between thickened virgae.

The linear-elliptic to linear-lanceolate with subcapitate to capitate shape and size of *K. subtilissima* matches *K. neocaledonica* Moser, Metzeltin & Lange-Bertalot, and *K. krasskei* Metzeltin & Lange-Bertalot, but the formation of the valve ends, and the central area are different. The interruption of the striae with vimenes between virgae (akin to *Brachysira* Kützing) is distinct for this species which should be compared to *Kobayasiella odakae* (Skvortzov) Lange-Bertalot with a similar structural formation. *Kobayasiella subtilissima* is distinguished from *K. odakae* by a smaller valve surface depression around the central area, the presence of small projections off the virgae, and the more random disruption of the striae.

Kobayasiella tursujuqensis sp. nov. (Figs 3A-J; 7A-F)

Holotype. — **Canada**. Québec, Lake 16-H, 56°15'10"N, 74°4'23"W, 256 m a.s.l., 16.VIII.2015, D. Antoniades (microscope slide designated as the holotype, holo-, CANA[CANA 129458]).

Isotype. — **Canada**. Québec, Lake 16-H, 56°15'10"N, 74°4'23"W, 256 m a.s.l., 16.VIII.2015, D. Antoniades (iso-, ANSP[ANSP-GC68067]).

Type locality. — **Canada**. Québec, Lake 16-H, 56°15'10"N, 74°4'23"W, 256 m a.s.l.

Etymology. —The epithet 'tursujuqensis' is named in recognition of Tursujuq National Park.

Ecology and distribution. — *Kobayasiella tursujuqensis* sp. nov. was found in eight lakes. The species was present in low relative abundances (mean 0.3%) with a maximum of 5.5% in Lake 16-H. No environmental distribution pattern can be distinguished related to water chemistry. However, this species seems to be more abundant in acidic waters (Appendix 3), with a pH optimum of 5.87, and in low specific conductivities (Appendix 1).

Registration. — http://phycobank.org/103918.

Description

Frustules rectangular and narrow in girdle view. Valves small, linear to linear-lanceolate with subrostrate to subcapitate apices. Valve dimensions (n = 12): length 17-19 µm, width 3-4 µm and striae 42-48 in 10 µm (SEM measurement). External valve face flat. Axial area linear to lanceolate and narrow. Central area absent, with 7-8 striae orientated between proximal raphe fissures. Raphe linear, with kink-like irregularity halfway between mid-valve and apex (Fig. 7A); externally, central raphe fissures widely spaced, linear expanded with rounded ends. Terminal raphe fissures curved, deflected, not hooked, to secondary side of valve opening with an external elliptic to funnel-like depression (Fig. 7D). Internally, raphe on a thickened sternum, straight, with no kink-like regularity. Proximal raphe fissures T-shaped

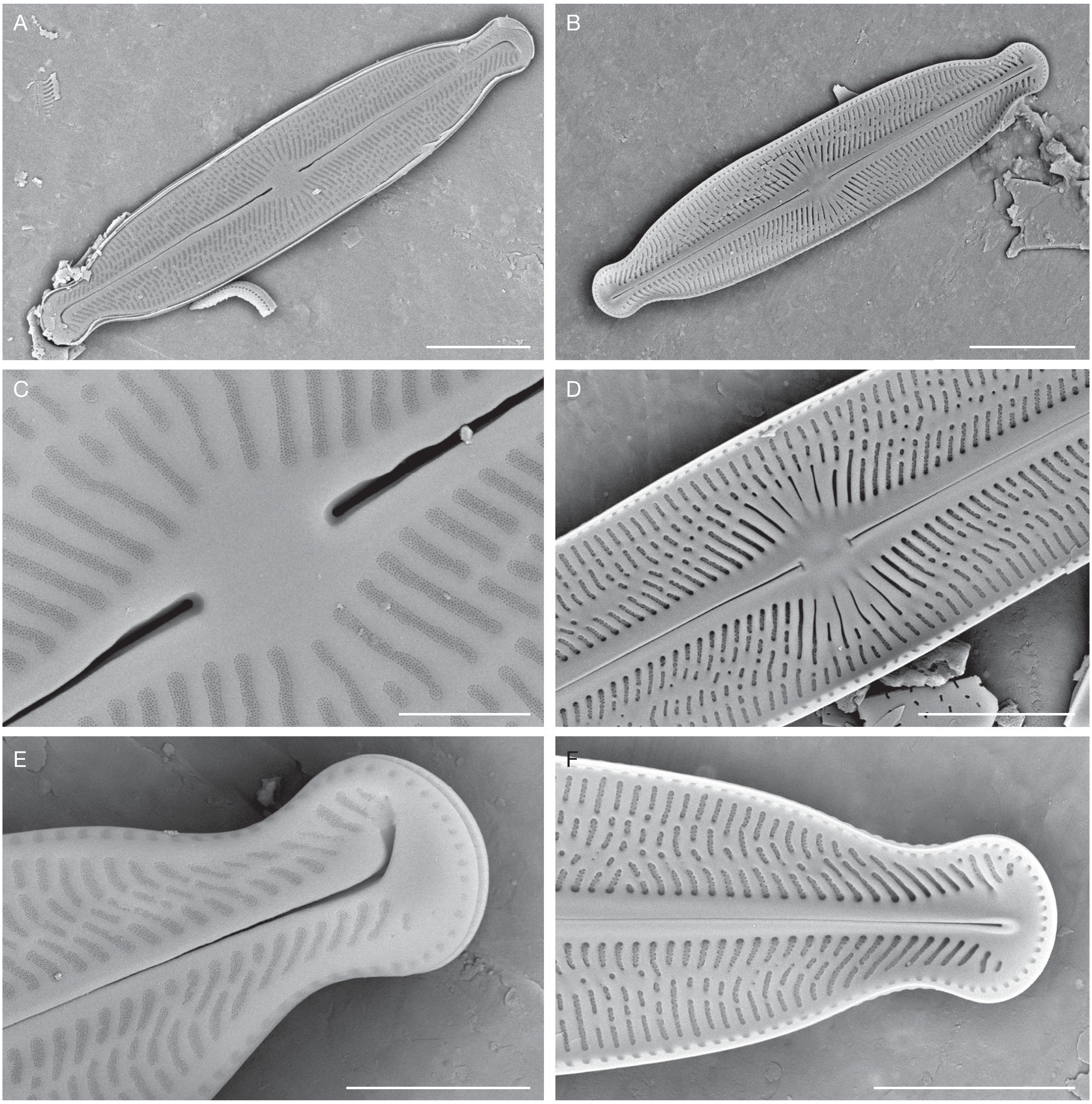

Fig. 6. — SEM images of *Kobayasiella subtilissima* (Cleve) Lange-Bertalot: **A**, external view of the complete valve; **B**, internal view of the complete valve; **C**, external view of central area showing the multiseriate poroid covers between irregular formed virgae; **D**, internal view of the central area showing T-shaped proximal fissures and irregular orientated areolae; **E**, external view of the valve apex showing a partially curved proximal fissure opening into an elliptic surface depression; **F**, internal valve view of the apex. Helictoglossa expanded onto a highline apex. Areolae continue around the apex. Scale bars: A, B, 5 μm; C, 1 μm; D, F, 3 μm; E, 2 μm.

and elevated on a central nodule (Fig. 7F). Terminal fissures end on elongated helictoglossae, isolated from apex mantle (Fig. 7E). Striae strongly radiate at mid-valve to strongly convergent at apices. A thickened valve margin separates valve face striae from mantle striae. From mid-valve to Voigt fault striae change from straight to flexed halfway between axial area and valve margin; from Voigt fault to apex striae change from flexed to straight. Mantle striae separated by thick hyaline ridge at valve face/mantle junction and not continuous around apices. Externally, striae sometimes expanded around central area, occluded with 4-8 rows of pores. Distinct Voigt faults on primary and secondary side of valve at ⅔ distance between mid-valve to apex (Fig. 7D). Internally, multiseriate pores positioned between thickened virgae.

This taxon is similar in valve outline to *K. parasubtilissima* but smaller, the apices are rostrate to subcapitate (not capitate as in *K. parasubtilissima*), the central raphe ends are closer together, the external terminal fissures are more hook-like with a larger grooved opening on the external face, and the

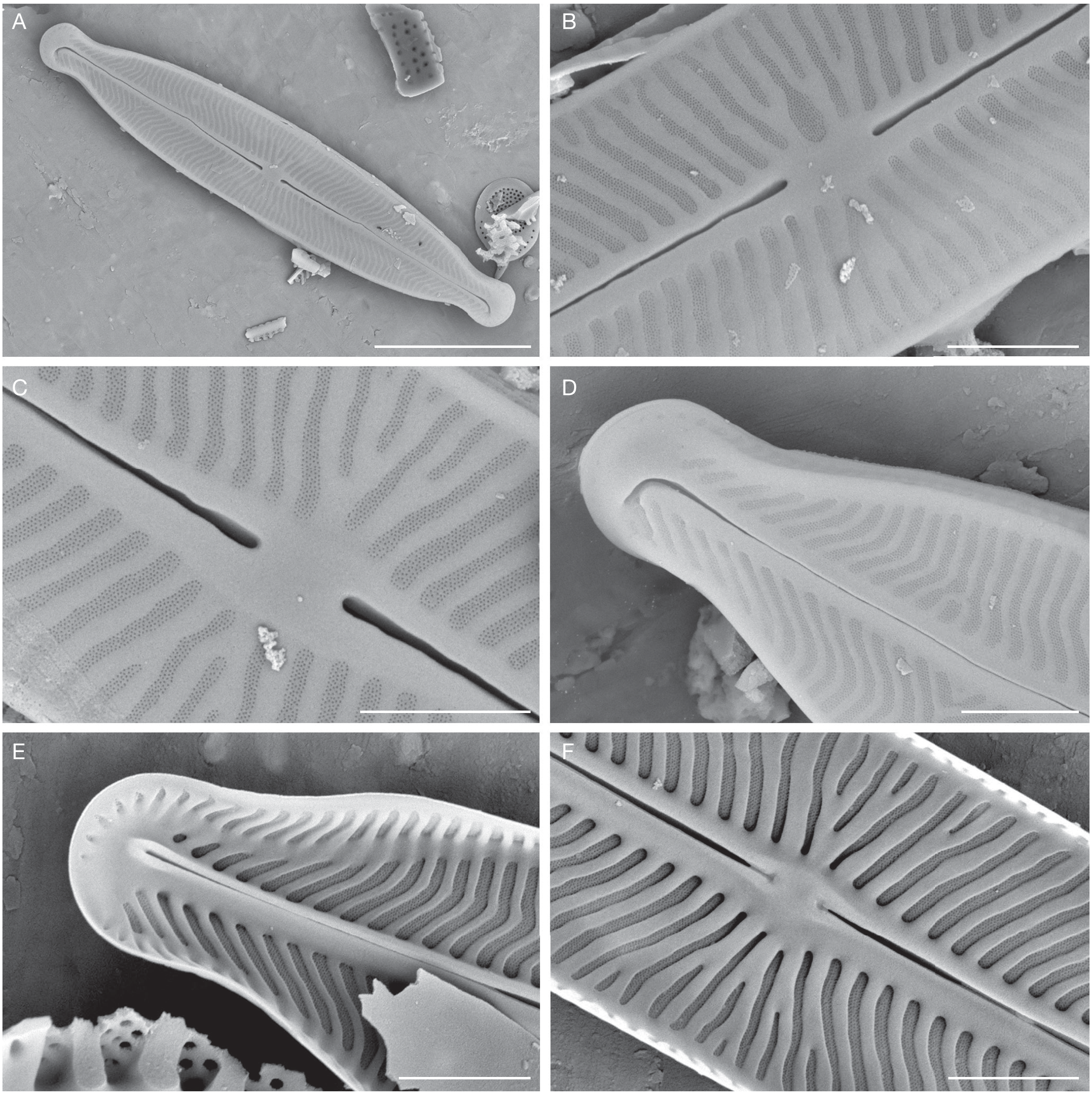

FIG. 7. — SEM images of *Kobayasiella tursujuqensis* sp. nov.: **A**, external view of the complete valve; **B**, **C**, external views of the central area showing the multiseriate poroid covers between irregular formed virgae; **D**, external view of the valve apex showing a bent proximal fissure opening into an irregular surface depression; **E**, internal valve view of the apex. Helictoglossa expanded onto a highline apex. Areolae interrupted around the apex; **F**, internal view of the axial and central areas with T-shaped proximal fissures with a central surface depression between the fissures. Scale bars: A, 5 µm; B-F, 1 µm.

internal virgae do not have silica projections into the striae. Finally, in some specimens the width of individual striae may vary, even forming bulbous expansions (Fig. 6C) around the central area. Other less similar unknown taxa for comparison include *Kobayasiella* species Nr 94/6-9 (?nov.) and *Kobayasiella* species Nr 94/6-9 (?nov.) from the Krasske material collected from Brazil (Metzeltin & Lange-Bertalot 1998). The current described size range of 17-19 µm is likely not the complete range, which is yet to be determined.

Kobayasiella pseudostauron
(Lange-Bertalot) Lange-Bertalot
(Figs 3K-T; 8A-G)

Iconographia Diatomologica 6: 272-275 (Lange-Bertalot 1999). — *Naviculadicta pseudostauron* Lange-Bertalot *in* Lange-Bertalot & Metzeltin, *Iconographia Diatomologica* 2 : 87-88 (Lange-Bertalot & Metzeltin 1996).

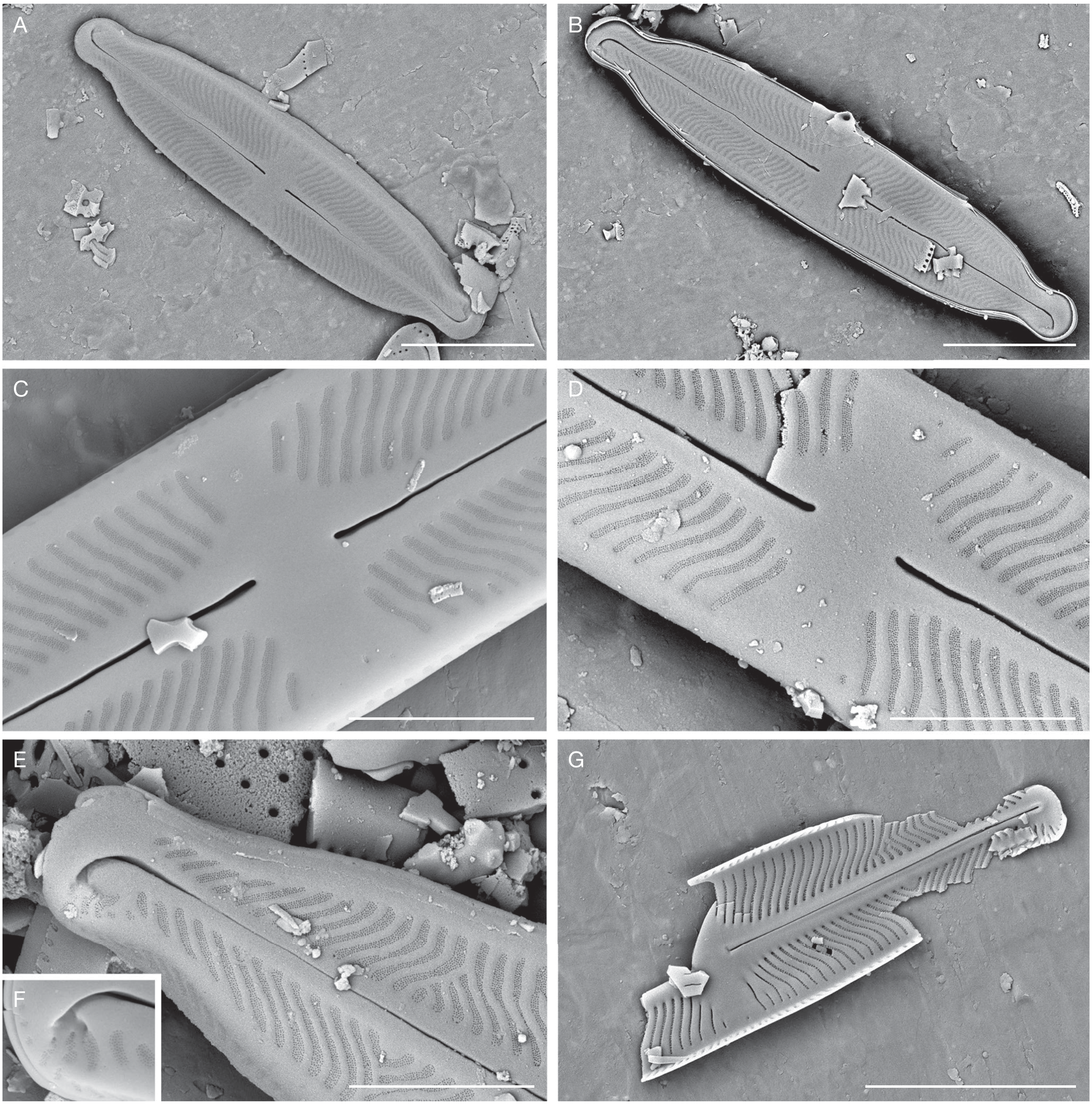

Fig. 8. — SEM images of *Kobayasiella pseudostauron* (Lange-Bertalot) Lange-Bertalot: **A**, **B**, external views of the complete valve; **C**, **D**, external views of the central area showing a stauros fascia and the multiseriate poroid covers over the striae between virgae; **E**, external view of the valve apex showing a curved proximal fissure opening into an irregular surface depression; **F**, magnified view of the terminal raphe fissure; **G**, internal view of a broken valve showing T-shaped proximal fissure and elongated helictoglossa. Scale bars: A, B, G, 5 µm; C-E, 2 µm.

Ecology and distribution. — *Kobayasiella pseudostauron* was commonly observed but not abundant in Tursujuq National Park, where it was found in 26 lakes with a mean relative abundance of 0.5% and a maximum abundance of 2.9% in lakes T2-D and 18-W. No clear autecological patterns were distinguishable. This species was found in circumneutral waters, with a pH optimum of 6.56 (Appendix 3). The type locality for this species is Julma-Ölkyy (Finland), which shows similar water conditions to those of Tursujuq Park: oligotrophic and weakly alkaline. *Kobayasiella pseudostauron* has a circumpolar distribution.

Description

The frustules are rectangular and narrow in girdle view. The valves exhibit a linear to linear-lanceolate shape with subrostrate to subcapitate to capitate protruding ends. Based on a sample size of 12, the valve dimensions range from a length of 19 to 22.5 µm and a width of 3.5 to 4.0 µm. The stria density is 38-40 in 10 µm. The external valve face is flat. The axial area is linear to lanceolate and narrow. The central area is a large rectangular to stauros-fascia, which may or may not have small marginal striae (Fig. 8A, C, D). The raphe is linear, with a kink-like irregularity halfway between the mid-valve and apex (Fig. 8A, B). Externally, the central raphe fissures are widely spaced and exhibit a linear expansion with indistinct rounded ends (Fig. 8C, D). The terminal raphe fissures are curved, deflected, not hooked, and located on the secondary side of the valve opening, with an external elliptic to funnel-like depression (Fig. 8E, F). Internally, the raphe is located on a thickened sternum and appears straight, without a kink-like irregularity (Fig. 8G). The proximal raphe fissures are T-shaped, and the terminal fissures end on small elevated helictoglossae, isolated from the apex mantle (Fig. 8G). The striae are strongly radiate at the mid-valve and become strongly convergent at the apices, with four to six rows of pores per stria. A thickened valve margin separates the striae on the valve face from the striae on the mantle. From the mid-valve to the Voigt fault, the striae became straight to flexed halfway between the axial area and valve margin. From the Voigt fault to the apex, the striae became flexed to straight. Distinct Voigt faults are present on both the primary and secondary sides of the valve, located at ⅔ of the distance between the mid-valve and apex (Fig. 8E, G). The striae on the mantle are reduced and continuous around the apices. The striae are covered with four to six rows of small multiseriate pores. Internally, the pores are positioned between thickened virgae ribs.

The specimens of *Kobayasiella pseudostauron* from Tursujuq National Park are at the bottom of the size range, with slightly smaller (19-22.5 vs 20-24 µm) and narrower (3.5-4.0 vs 4.0-4.7 µm) valves compared to specimens from the type locality. Some of the LM images from the type description have visible striae (e.g. Lange-Bertalot & Metzeltin 1996: pl. 35, figs 11, 13) which may suggest that this taxon has a wider stria range than reported (37-39 in 10 µm). The SEM internal views of the central area and the capitate ends match our SEM images. *Kobayasiella pseudostauron* is similar to *K. jaagii* (F.Meister) Lange-Bertalot: two small *Kobayasiella* taxa with a large central area or fascia. *Kobayasiella jaagii* is a larger species (24-27 vs 19-24 µm) and broader (5 µm vs 3.5-4.5 µm) with a lower stria density. Furthermore, *K. jaagii* has rostrate apices while *K. pseudostauron* has subcapitate to capitate apices and a full stauros-like central fascia. Specimens identified as *K. jaagii* from western North America are larger than the original description and bluntly rostrate, compared to the attenuated rostrate apices of *K. jaagii* in the original drawing of Meister (Bahls 2013), which is in line with the broader concept of the species presented by Germain (1981) and Krammer & Lange-Bertalot (1986).

Kobayasiella micropunctata (Germain) Lange-Bertalot (Figs 3U-AM; 9A-F)

Iconographia Diatomologica 6: 267 (Lange-Bertalot 1999). — *Navicula subtilissima* var. *micropunctata* Germain, *Flore des diatomées – Diatomophycées – eaux douces et saumâtres du Massif armoricain et des contrées voisines d'Europe occidentale*: 234 (Germain 1981). — *Navicula micropunctata* (Germain) Kobayasi & Nagumo, *The Botanical Magazine, Tokyo* 101 (1063): 247 (Kobayasi & Nagumo 1988).

Ecology and distribution. — *Kobayasiella mircopunctata* was the most commonly found *Kobayasiella* species in our study, present in 33 lakes. However, its mean relative abundance was only 0.8%, with a maximum of 6.2% in Lake 16-F. No clear distributional pattern was distinguished according to water chemistry conditions. However, a medium alkalinity level seems to be consistent for this species. Mg and Na concentrations were linked to the distribution with respective optima at 0.87 mg/L and 0.34 mg/L. Kobayasi & Nagumo (1988) observed this species from Imandra Lappmark (Russia) and Japan in waters with circumneutral pH and low conductivity (131 µS/cm). In North America, *K. micropunctata* has been reported from Montana (United States) in waters with pH 8.46 and low conductivity (19 µS/cm), indicative of fluctuating pH (Bahls 2012a). This species at present has a global distribution in northern and subalpine environments.

Description

The frustules are rectangular and narrow in girdle view. The valves exhibit a linear-lanceolate shape with more or less narrow subcapitate to capitate protruding ends. Based on a sample size of 22, the valve dimensions range from a length of 17 to 24.5 µm and a width of 3.5 to 6 µm. The stria density varies from 40 to 44 in 10 µm. The axial area is lanceolate and narrow. The central area is elliptic and occupies more than half the width of the valve, with seven to eight long and short striae between the proximal raphe ends (Fig. 9C). Externally, the valve face is flat. The raphe is linear, with a kink-like irregularity halfway between the mid-valve and apex (Fig. 9A, B). Externally, the central raphe fissures are widely spaced and linearly expanded, with enlarged rounded ends (Fig. 9C). The terminal raphe fissures are hooked to the secondary side of the valve opening and exhibit a small external funnel-like surface depression (Fig. 9D). Internally, the raphe is located on a thickened sternum. The terminal fissures end on small elongated helictoglossae, isolated from the apex mantle (Fig. 9E). The striae are strongly radiate at the mid-valve and become strongly convergent at the apices. The mantle striae are interrupted by a thick hyaline ridge at the valve face/mantle junction. The striae on the mantle apex are reduced and continuous around the apices. Distinct Voigt faults are present on both the primary and secondary sides, close to the apex. The striae are covered with four rows of small multiseriate pores. Internally, the multiseriate pores are positioned between thickened virgae. The cingulum is composed of finely silicified open wide copulae bands, and the copulae feature two rows of areolae covered with fine poroid occlusions. At the base of the copula, there is a fringe of fine pores (Fig. 9F).

Our taxon, with a linear-lanceolate outline and subcapitate to capitate protruding ends with hooked terminal raphe fissures, matches the species *K. micropunctata* (synonym: *Navicula subtilissima* var. *micropunctata* (Germain) Kobayasi & Nagumo). In the original description, Germain (1981) reported his illustrated valve (in TEM) to be 2 µm wide, but based on the magnification it is actually 3.8 µm wide, which is in line with the specimens of Kobayasi & Nagumo (1988) and those of this study. Kobayasi & Nagumo (1988) emended the species with detailed SEM and TEM images. In

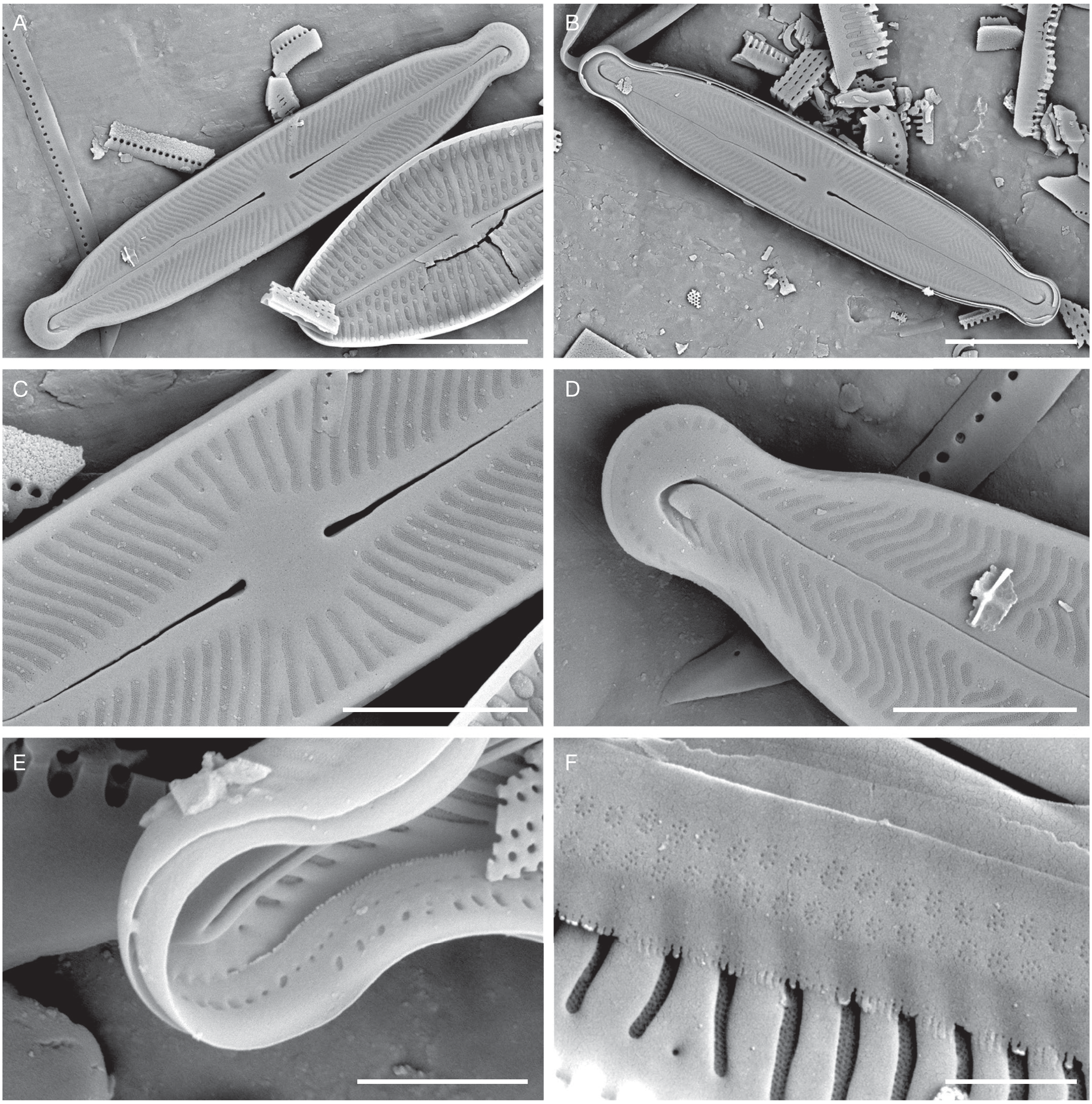

FIG. 9. — SEM images of *Kobayasiella micropunctata* (Germain) Lange-Bertalot: **A**, **B**, external views of the complete valve; **C**, external view of the central area showing the multiseriate poroid covers over the striae between virgae; **D**, external view of the valve apex showing a hooked terminal fissure opening into an irregular surface depression; **E**, internal view of the apex with magnified view of the terminal elongated helictoglossa; **F**, internal view of a copula showing two rows of pores occluded with small round pores. Scale bars: A, B, 5 µm; C, D, 2 µm; E, 1 µm; F, 500 nm.

their specimens the broad central area is documented along with the absence of virgae projections and hooked terminal raphe fissures. Kobayasi & Nagumo (1988) did not examine the type material of Germain, but looked at materials from Imandra Lappmark (Russia) and Japan. Species with similar valve outlines but with a larger size include *K. pseudostauron*, *K. tursujuqensis* sp. nov. and *K. subtilissima*. In LM, this taxon is distinguished by size, subcapitate apices and a broad central area.

Genus *Adlafia* Moser, Lange-Bertalot & Metzeltin

Adlafia bryophila (J.B.Petersen) Lange-Bertalot (Figs 10A-R; 11A-F)

Bibliotheca Diatomologica 38: 89 (Moser *et al*. 1998). — *Navicula bryophila* J.B.Petersen, *The Botany of Iceland* 2: 388 (Petersen 1928).

ECOLOGY AND DISTRIBUTION. — *Adlafia bryophila* was commonly observed in Tursujuq National Park, found in 23 lakes. It was generally

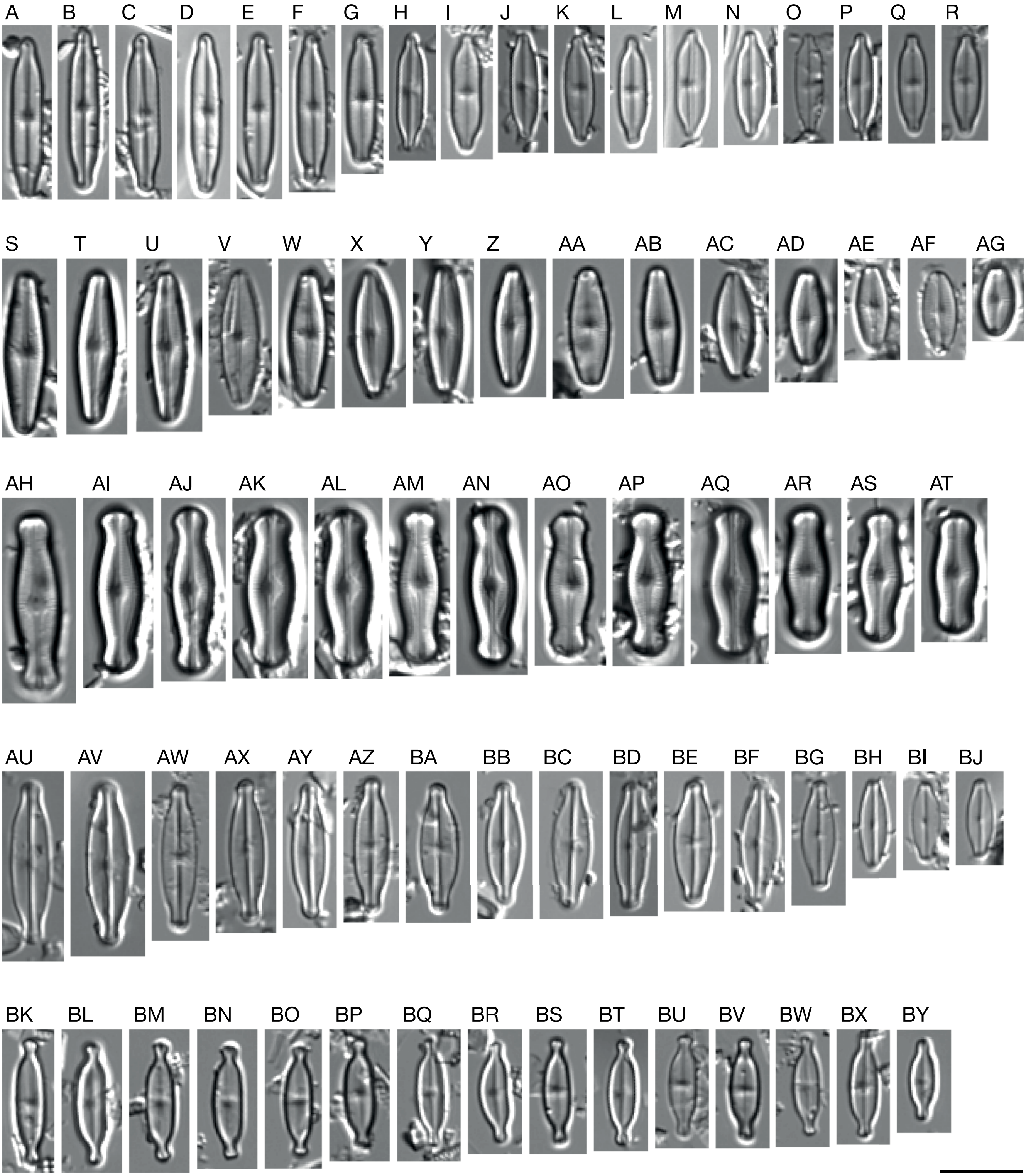

FIG. 10. — Light micrograph diminution series of *Adlafia* Moser, Lange-Bertalot & Metzeltin, *Sellaphora* Mereschkowski and *Nupela* Vyverman & Compère species: **A**-**R**, *Adlafia bryophila* (J.B.Petersen) Lange-Bertalot; **S**-**AG**, *Adlafia umiujaqensis* sp. nov.; **AH**-**AT**, *Adlafia ossiformis* sp. nov.; **AU**-**BJ**, *Sellaphora vincentiana* sp. nov.; **BK**-**BY**, *Nupela tenuicephala* (Hustedt) Lange-Bertalot. Scale bar: 10 μm.

present in low relative abundances, with a mean of 0.5% and maximum of 2.7%. No distributional pattern was found in relation to general environmental conditions, but it appears to be a circumneutral species (Appendix 3). Moreover, its distribution may be affected by Mg and dissolved inorganic carbon (DIC) concentrations (Appendices 4; 5). This taxon has been identified from the circumpolar Arctic region.

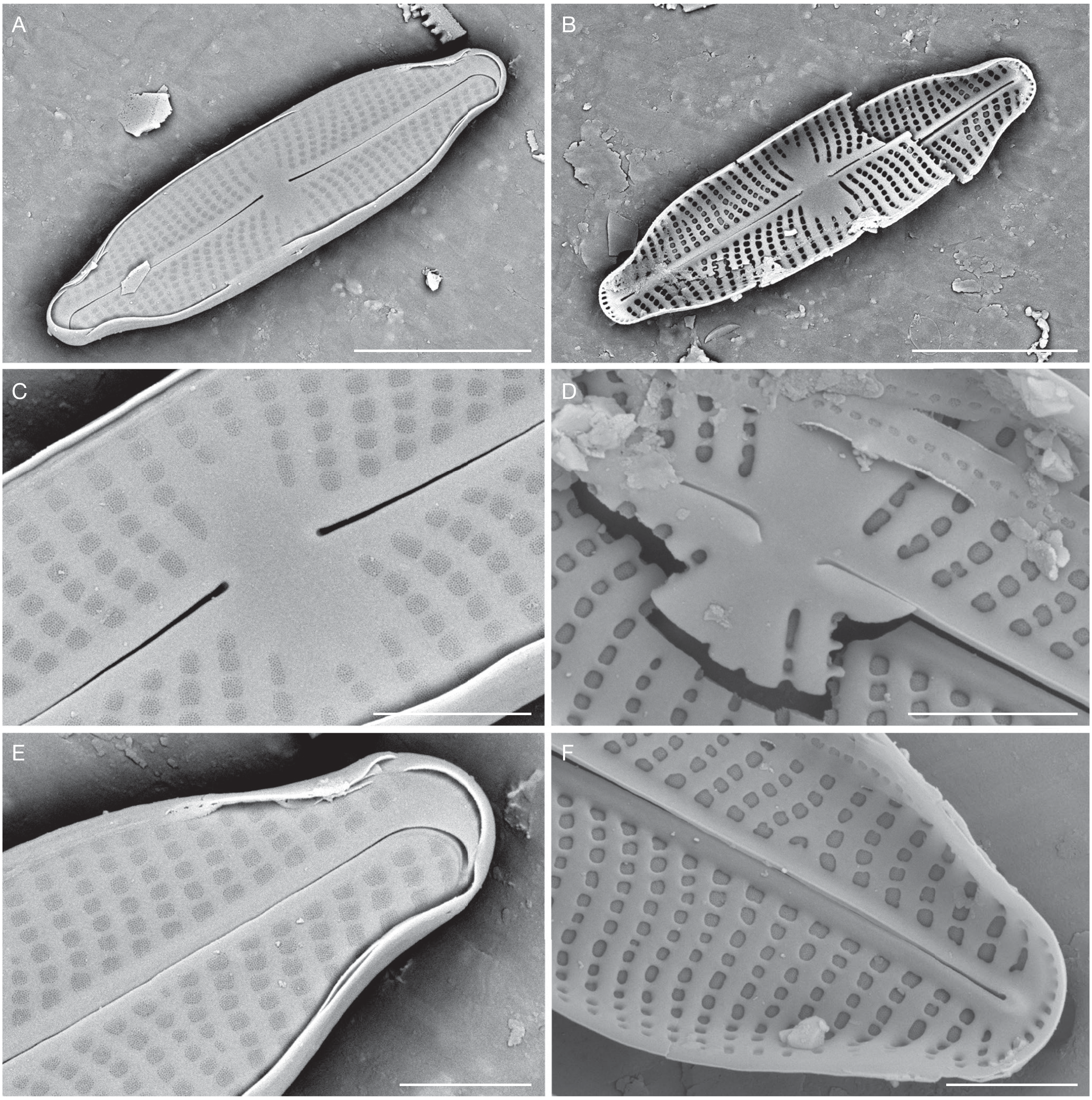

Fig. 11. — SEM images of *Adlafia bryophila* (J.B.Petersen) Lange-Bertalot: **A**, external view of the complete valve; **B**, internal view of the complete valve; **C**, external view of the central area showing the multiseriate poroid covers over the areolae; **D**, internal view of the central area showing hooked proximal fissures to one side. Copula with one row of large occluded pores; **E**, external view of the apex with a curved fissure onto the mantle. A curved ridge follows the fissure; **F**, internal view of the apex with a small elevated helictoglossa. Areolae are continuous around the apex. Scale bars: A, B, 5 µm; C, D, 2 µm; E, F, 1 µm.

Description

The frustules are rectangular and narrow in girdle view. The valves exhibit a linear to linear-lanceolate shape with rostrate ends. Based on a sample size of 28, the valve dimensions range from a length of 11.5 to 19 µm and a width of 3 to 4 µm. The stria number ranges from 28 to 30 in 10 µm. Externally, the valve face is flat. The axial area is weakly curved, lanceolate, and narrow. In LM, the axial area is almost indistinct. The central area is large, round to elliptic, favouring one side, and it possesses three to four marginal striae (Fig. 11C). The raphe is linear, without any kink-like irregularity halfway between the mid-valve and apex (Fig. 11A). Externally, the central raphe fissures are linearly expanded with small pores slightly deflecting to one side. The terminal raphe fissures are curved and extend down onto the upper region of the mantle (Fig. 11E). Adjacent to the terminal raphe, there is a ridged groove that runs from the valve face to the upper mantle. Internally, the raphe is located on an elevated sternum and appears straight, without any kink-like irregularity. The proximal raphe fissures are deflected to the same side (Fig. 11D). The terminal fissures end on small elevated helictoglossae, isolated from the apex mantle (Fig. 11F). The striae are radiate at the mid-valve and become convergent at the apices, and they are continuous from the valve face to the mantle. The striae are arched close to the mid-valve, and from the Voigt fault to the apex, they become straight. Voigt faults on the secondary side of the valve are located at approximately ⅔ of the distance between the mid-valve and apex. The striae are continuous around the apices. Areolae are round to rectangular, with five to six per stria and two to four at the apices (Fig. 11E, F). Externally, the areolae are covered with a fine poroid velum that exhibits eight to ten circular rows of small pores. Internally, the multiseriate pored velum is positioned between thickened virgae. *Adlafia bryophila* was first identified from Iceland by J.B. Petersen based on a small linear to linear-elliptic valve with distinct rostrate apices and fine striae.

The specimens from Tursujuq National Park are similar in size shape and form, but with a lower stria density (28-30 in 10 µm versus *c.* 35 in 10 µm for *Navicula bryophila* (synonym: *A. bryophila*)). Petersen (1928) illustrated a line drawing with visible striae which would not be possible in the LM without specialized optics with 35 striae in 10 µm, so the stria density is also possibly less than 30 in 10 µm. In SEM, our specimens show the terminal raphe ends curving down onto the mantle, while the areolae have surface volate covers with fine poroids, which allows identification of this taxon as belonging to *Adlafia*. We appear to have two forms, one with a smaller central area and a second, more abundant form with a larger central area. There are a number of taxa with this general valve shape, including *A. brockmanii* (Hustedt) K.Bruder, *A. coringii* Metzeltin & Lange-Bertalot, *A. drouetiana* (Patrick) Metzeltin & Lange-Bertalot, *A. muscora* (Kociolek & Reviers) Moser, Lange-Bertalot & Metzeltin, *A. parabryophila* (Lange-Bertalot) Moser, Lange-Bertalot & Metzeltin, *A. pseudobaicalensis* Kulikovskiy & Lange-Bertalot, and *A. suchlandtii* (Hustedt) Moser, Lange-Bertalot & Metzeltin. *Adlafia coringii* and *A. drouetiana* are larger and broader (more elliptic), while *A. parabryophila* is constricted with a lower stria density. *Adlafia pseudobaicalensis* and *A. suchlandtii* are more elliptic with weakly rostrate apices. The differentiation of *A. bryophila* from *A. brockmannii* and *A. muscora* is less clear and needs further study, although the central area of *A. brockmannii* is a full fascia, and *A. muscora* has less attenuated rostrate ends.

Adlafia umiujaqensis sp. nov.
(Figs 10S-AG; 12A-F)

Holotype. — **Canada**. Québec, Lake 22AA, 56°33'24"N, 76°28'47"W, 128 m a.s.l., 22.VIII.2015, D. Antoniades (microscope slide designated as the holotype, holo-, CANA[CANA 129481]).

Isotype. — **Canada**. Québec, Lake 22AA, 56°33'24"N, 76°28'47"W, 128 m a.s.l., 22.VIII.2015, D. Antoniades (iso-, ANSP[ANSP-GC68068]).

Type locality. — **Canada**. Québec, Lake 22AA, 56°33'24"N, 76°28'47"W, 128 m a.s.l.

Etymology. — The epithet 'umiujaqensis' is named for the Inuit village nearest to the lake where the species was observed.

Ecology and distribution. — *Adlafia umiujaqensis* sp. nov. was found in three lakes of this study, CEN-O, 22-Z and 22-AA. While it represented 7.1% of the diatom assemblage in lake 22-AA, it reached only 1.9% and 0.6% relative abundance, respectively, in lakes 22-Z and CEN-O. The low number of occurrences obscured any potential autecological patterns of this species (Appendices 1; 2; 3).

Registration. — http://phycobank.org/103919.

Description

Frustules rectangular and narrow. Valves linear-elliptic to elliptic with rounded ends. Valve dimensions (n = 25): length 8-18.5 µm, width 4-4.5 µm and 30-33 striae in 10 µm. External valve face flat. Axial area weakly curved to linear and narrow. Central area round to elliptic, with 3-4 marginal striae between proximal raphe ends. Raphe linear to curved, with no kink-like irregularity halfway between mid-valve and apex (Fig. 12A, B). Externally, central raphe fissures narrow and not distinguished. Terminal raphe fissures curved down onto upper region of mantle (Fig. 12D). Ridged groove present adjacent to terminal raphe from valve face to upper mantle. Internally, raphe on evident sternum, straight, with no kink-like irregularity. Proximal raphe deflected strongly to one side of central nodule; nodule sometimes with surface depression or with an isolated pore (Fig. 12E). Terminal fissures end on small elevated helictoglossae, isolated from apex mantle. Internal hyaline area of apex more developed on secondary side. Striae more or less straight, weakly radiate at mid-valve to parallel or weakly convergent at apices and continuous from valve face to mantle. Voigt faults on secondary side of valve ⅔ of distance between mid-valve and apex. Striae continuous around apices. Areolae round to rectangular, 5-7 per stria, 3-4 at apices. Areolae covered by a fine poroid velum with 8-11 circular rows of small pores.

This taxon has a simple linear-elliptic to elliptic shape that could be assigned to many small taxa across different genera. The surface volate covers of the areolae, curved terminal fissures externally, simple bent proximal fissure internally and small terminal helictoglossae distinguish this as an *Adlafia* taxon. Electron microscopic examination of specimens may at times be necessary to document this species. *Navicula muralis* Grunow (synonym: *A. minuscula* var. *muralis* (Grunow) Lange-Bertalot) has a similar shape and the type material needs further study. Krammer & Lange-Bertalot (1986) present a representative TEM of a valve, under the name *N. suchlandtii sensu lato*, that matches our taxon.

Adlafia ossiformis sp. nov.
(Figs 10AH-AT; 13A-H)

Holotype. — **Canada**. Québec, Lake 22AA, 56°33'24"N, 76°28'47"W, 128 m a.s.l., 22.VIII.2015, D. Antoniades (microscope slide designated as the holotype, holo-, CANA[CANA 129481]).

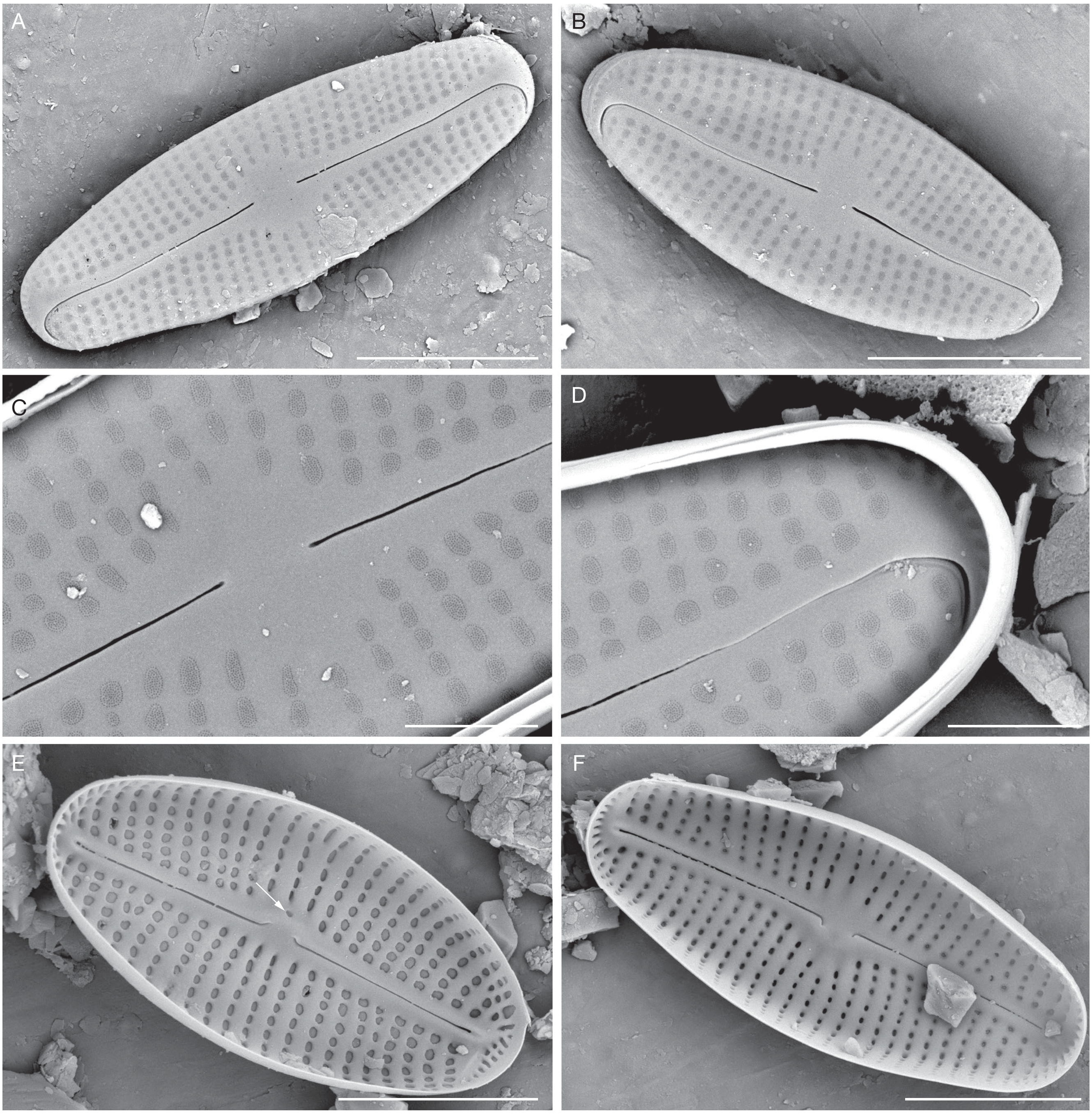

Fig. 12. — SEM images of *Adlafia umiujaqensis* sp. nov.: **A**, **B**, external views of the complete valve; **C**, external view of the central area showing the multiseriate poroid covers over the areolae; **D**, external view of the apex with a curved fissure onto the mantle. A curved ridge follows the fissure; **E**, **F**, internal views of the valve. Proximal fissures bent to one side and terminal fissures small and elevated. The central nodule is elevated and an isolated pore (**arrow**) may be present. Scale bars: A, B, 4 µm; C, D, 1 µm; E, F, 3 µm.

Isotype. — **Canada**. Québec, Lake 22AA, 56°33'24"N, 76°28'47"W, 128 m a.s.l., 22.VIII.2015, D. Antoniades (iso-, ANSP[ANSP-GC68069]).

Type locality. — **Canada**. Québec, Lake 22AA, 56°33'24"N, 76°28'47"W, 128 m a.s.l.

Etymology. — The epithet 'ossiformis' is Latin, describing this species' bone-shaped valves.

Ecology and distribution. — This species was found only in 22-AA lake of the study, where it represented 4% of the diatom assemblage. Lake 22-AA had the highest TP concentration in the dataset (23.4 µg/L).

Registration. — http://phycobank.org/103920.

Description

Frustules rectangular and narrow in girdle view. Valves elliptic at mid-valve with broad capitate ends. Valve dimensions (n = 20): length 13.5-20.5 µm, width 4.5-5.5 µm and 30-35 striae in 10 µm. External valve face flat, margin rounded. Axial area slightly curved to linear and narrow. Central area round to elliptic, > ½ width of valve, with 5-7 marginal striae between proximal raphe endings. Raphe linear, with no kink-like irregularity halfway between mid-valve and apex (Fig. 13A); externally, central raphe fissures widely spaced with small indistinct ends bent to one side (Fig. 13C). Terminal raphe fissures curved down onto upper region of mantle (Fig. 13G). A weakly formed groove present parallel to raphe on mantle up to valve face. Internally, raphe on small sternum, straight, with no kink-like irregularity (Fig. 13B). Proximal raphe fissures bent and deflected on a raised nodule (Fig. 13D). One surface depression present on central nodule (Fig. 13D, E). Terminal fissures end on small elongated helictoglossae, isolated from apex mantle (Fig. 13H). Hyaline area of terminal nodule more developed on secondary side of valve. Striae continuous, straight to weakly arched from valve face to mantle, more widely spaced around central area. Voigt faults weak to indistinct on secondary side of valve ⅔ of distance between mid-valve and apex. Striae continuous around base of apices. Areolae round to rectangular, 4-6 per stria. Areolae covered with a fine poroid velum with 8-9 circular rows of small pores around outside edge and linear rows on inner area. Internally, areolae recessed between virgae.

Adlafia ossiformis sp. nov. has a shape that is easily confused in LM with *Psammothidium ventralis* (Krasske) Bukhtiyarova & Round and *Sellaphora guyanensis* Metzeltin & Lange-Bertalot, but careful examination of both valves will make species differentiation possible.

Genus *Sellaphora* Mereschkowski

Sellaphora vincentiana sp. nov.
(Figs 10AU-BJ; 14A-F)

Holotype. — **Canada**. Québec, Lake 22AA, 56°33’24”N, 76°28’47”W, 128 m a.s.l., 22.VIII.2015, D. Antoniades (microscope slide designated as the holotype, holo-, CANA[CANA 129481]).

Isotype. — **Canada**. Québec, Lake 22AA, 56°33’24”N, 76°28’47”W, 128 m a.s.l., 22.VIII.2015, D. Antoniades (iso-, ANSP[ANSP-GC68070]).

Type locality. — **Canada**. Québec, Lake 22AA, 56°33’24”N, 76°28’47”W, 128 m a.s.l.

Etymology. — The epithet ‘vincentiana’ is named in honour of our dear colleague Warwick Vincent, whose contributions to diatom research are substantial and cannot be measured.

Ecology and distribution. — This species was found in two lakes of the study: 22-Z and 22-AA. It reached 4.6% relative abundance in lake 22-AA and only 0.6% in 22-Z. The low number of occurrences prevented us from discerning clear relationships with lake chemistry, but both sites where it occurred had circumneutral conditions, and Lake 22-AA had the highest TP concentration in the dataset.

Registration. — http://phycobank.org/103921.

Description

Frustules rectangular and narrow in girdle view. Valves linear-elliptic to elliptic with restricted rostrate ends. Valve dimensions (n = 25): length 8-18.5 µm, width 2.5-4.5 µm. External valve face flat, margin rounded. The stria density is 49-51 in 10 µm. Axial area curved and narrow; external sternum raised. Central area weakly expanded, with 4-6 marginal striae between proximal raphe fissures, 1-2 striae shorter than the others (Fig. 14A-C). Raphe curved, with no kink-like irregularity halfway between mid-valve and apex; externally, central raphe fissures linearly expanded with rounded ends sometimes bent to primary side (Fig. 14B, C). Terminal raphe fissures bent down onto upper region of mantle, opening into a small circular depression (Fig. 14D). Internally, raphe on sternum, straight, with no kink-like irregularity. Proximal raphe fissures teardrop-shaped and positioned on raised central nodule (Fig. 14E); terminal fissures end on small helictoglossae, isolated from apex mantle (Fig. 14F). Striae more widely spaced around central area, and parallel throughout. Striae continuous, straight to weakly arched from valve face to mantle. Voigt faults indistinct. Striae continuous around apices. Areolae round to rectangular, 8-10 per stria, 3-4 at apices (Fig. 14D). Areolae covered with a recessed fine poroid velum with circular rows of small and almost indistinct pores around outside edge and random distribution on inner area. Areolae along axial sternum more evidently depressed. Internally, areolae between virgae weakly recessed with volate pore cover.

The small linear to linear-elliptic shape with subrostrate to rostrate apices is a common shape of many species and genera which creates confusion in identifications. Furthermore, the high striae counts may create confusion between *Adlafia*, *Eolimna* and *Sellaphora*. As a result, taxonomic confusion persists today when trying to distinguish taxa within these genera. After SEM study, the morphology of these valves is clearly aligned with the genus *Sellaphora*, with recessed volate occlusion of the areolae, raised external axial and terminal areas, distinctly larger areolae along the axial area, and bent terminal raphe fissures down onto the mantle. A distinct asymmetric internal central nodule also helps to distinguish this taxon from *Adlafia* and *Eolimna* species. *Sellaphora stauroneioides* (Lange-Bertalot) Vesela & Johansen is comparable to *Sellaphora vincentiana* sp. nov., but is larger, with clear hyaline areas at the apices and is more linear than linear-elliptic. Electron microscopic comparisons are needed to distinguish these small *Sellaphora* species. In addition, *Navicula arvensoides* Hustedt and *Sellaphora pseudoarvensis* (Hustedt) Wetzel & Ector are small taxa with similar valve outlines, linear valve margins and distinct rostrate or subcapitate apices (Simonsen 1987; Table 3). With no SEM examination of these taxa, detailed comparisons are limited to LM which shows a triundulate valve margin with broad rostrate apices, and visible striae in *N. arvensoides*; in contrast, *S. pseudoarvensis* has linear valve margins, curved raphe branches, no visible striae and subcapitate apices.

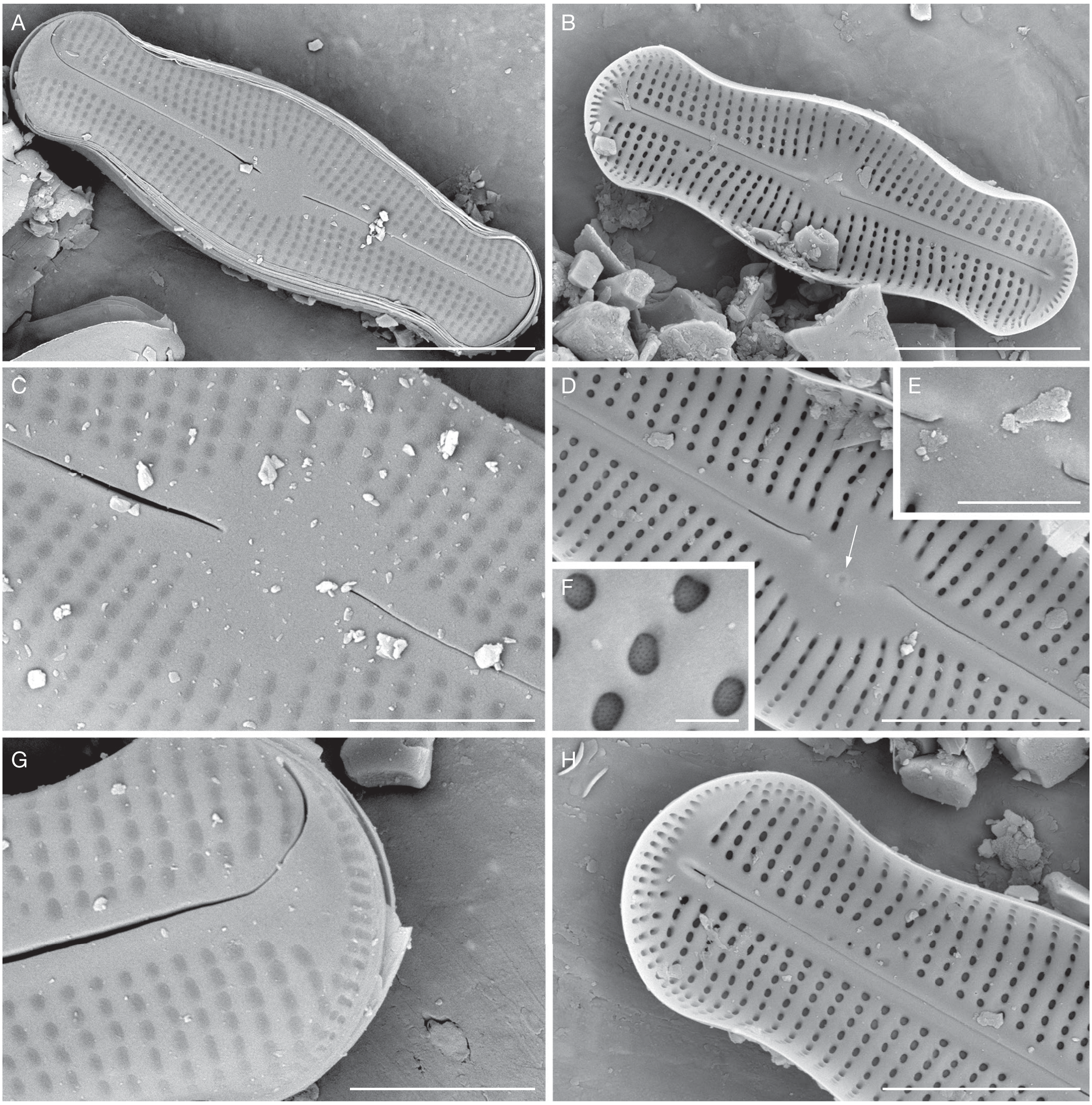

FIG. 13. — SEM images of *Adlafia ossiformis* sp. nov.: **A**, external view of the complete valve; **B**, internal view of the complete valve; **C**, external view of the central area showing small proximal raphe fissures and multiseriate poroid covers over the areolae; **D**, internal view of the central area with curved fissures and a ghost-areolae depression; **E**, magnification of the central area; **F**, magnification of areolae with recessed poroid volae; **G**, external view of the apex. Fissure bent down onto the mantle; **H**, internal view of the apex. The central nodule is elevated and an isolated pore (**arrow**) may be present. Scale bars: A, B, 5 μm; C, G, 2 μm; D, H, 3 μm; E, 1 μm; F, 300 nm.

Genus *Nupela* Vyverman & Compère

Nupela tenuicephala (Hustedt) Lange-Bertalot (Figs 10BK-BY; 15A-F)

Bibliotheca Diatomologica 27: 157 (Lange-Bertalot 1993). — *Navicula tenuicephala* Hustedt, *Archiv für Hydrobiologie* 39 (1): 113 (Hustedt 1942). — *Navicula tridentula* var. *tenuicephala* Cleve-Euler, *Kongliga Svenska Vetenskaps-Akademiens Handligar*, ser. 4, 4 (5): 190 (Cleve-Euler 1953).

Nupela paludigena (Scherer) Lange-Bertalot, *Bibliotheca Diatomologica* 27: 158 (Lange-Bertalot 1993). — *Anomoeoneis paludigena* Scherer, *Diatom Research* 3 (1): 149 (Scherer 1988).

ECOLOGY AND DISTRIBUTION. — *Nupela tenuicephala* was found in 14 lakes from Tursujuq National Park. It was not abundant, with a mean relative abundance of 1.1%, although lakes 16-H and 18-P

TABLE 3. — Comparative analysis of species characteristics of *Sellaphora vincentiana* sp. nov., *Navicula arvensoides* Hustedt and *Sellaphora pseudoarvensis* (Hustedt) C.E.Wetzel & L.Ector.

Species	Length (µm)	Width (µm)	Striae
Sellaphora vincentiana sp. nov.	8-18.5	2.5-4.5	49-51 in 10 µm
Navicula arvensoides Hustedt	10	4	*c.* 40 striae in 10 µm
Sellaphora pseudoarvensis (Hustedt) C.E.Wetzel & L.Ector	8-10	3	striae indistinct

had populations reaching 38.6 and 9.6% relative abundance. While there were no evident distribution patterns linked to water chemistry, this species was more prominent in low conductivity and acidic waters with a pH optimum of 5.9 (Appendix 3), and associated with low DIC and Mg (Appendices 4; 5). *Nupela tenuicephala* is common across eastern North America in acidic waters according to Siver & Hamilton (2011) (as *N. paludigena*), Fallu *et al.* (2000) (as *N. tenuicephala*), and Camburn & Charles (2000) (as *Anomoeoneis paludigena*).

DESCRIPTION

The frustules are rectangular and narrow in girdle view. The valves exhibit an asymmetric shape, being linear on the primary side and linear-elliptic on the secondary side, with constricted rostrate to capitate ends (Fig. 15A, B, C). The valve dimensions, based on a sample size of 25, range from a length of 9.5 to 14 µm and a width of 2.5 to 3.5 µm. The stria density is 54-55 in 10 µm. Externally, the valve face is flat, and the margin abruptly bends (not curves) towards the mantle. The axial area is linear to lanceolate and narrow. The central area is asymmetric, being elliptic on the primary side with four marginal striae, and it exhibits a slightly elevated fascia on the secondary side (Fig. 15A, C, D). The raphe is linear and curved, without any kink-like irregularity halfway between the mid-valve and apex. Externally, the central raphe fissures are linearly expanded with teardrop rounded ends (Fig. 15D). The terminal raphe fissures curve and bend, extending down to the lower mantle. Internally, the raphe is located on the sternum and appears straight. The proximal raphe fissures are small and hooked to the secondary side (Fig. 15E), while the terminal fissures end on small elevated helictoglossae, isolated from the apex mantle (Fig. 15F). The striae are parallel to weakly radiate close to the mid-valve, and they become parallel at the ends. On the valve face, the striae are straight to weakly arched and interrupted at the valve edge. Voigt faults on the secondary side of the valve are indistinct, located at approximately ⅔ of the distance between the mid-valve and apex. The striae are interrupted by the raphe at the apices. Areolae are round to rectangular, with five to six per stria on the secondary side and three to four on the primary side. They are covered with a poroid velum that exhibits fine circular rows of small pores.

This taxon was originally described by Hustedt as a *Navicula* species from Lapland, Abisko, Sweden. There were three slides with this taxon named by Simonsen (1987: 232) with one slide selected (P2/57, *Lapland 189*, Abisko, Tümpel) as the lectotype. The LM images of Simonsen and specimens from Bahls & Potapova (2015) match our specimens. Scherer (1988) also described a similar species (*Anomoeoneis paludigena*) from Georgia (United States), which was transferred to *Nupela* by Lange-Bertalot (1993) and later emended by Siver *et al.* (2007). At this time, *N. tenuicephala* is in synonymy with *N. paludigena*. See Siver & Hamilton (2011) for a more thorough discussion about *N. paludigena*. *Nupela tenuicephala* is also similar to *N. giluwensis* Vyverman & Compère, but is distinguished by the differences in outline, striae density and formation of the central area. Siver & Hamilton (2011) suggest there is little difference between *N. tenuicephala* (synonym: *N. paludigena*) and *N. giluwensis* and they propose a more thorough comparison between these taxa. Another similar species is *N. subinvicta* (Krasske) Lange-Bertalot observed from Chile, but this taxon is different from *N. tenuicephala* with respect to valve symmetry, the large capitate apices and a broad central area.

DISCUSSION

Small benthic species are taxonomically understudied due to issues related to low abundances, similar shapes and the inability to see fine morphological features with light microscopy. The genera *Kobayasiella*, *Adlafia*, *Nupela* and *Sellaphora* all contain small benthic species that are often difficult to distinguish even at the genus level. Furthermore, similar species are often found in the same communities at low abundances. In this study, 33% of the sites had three *Kobayasiella* species, 27% had two species, 21% had one species and 10.5% had four species. One site had five species and three sites had no *Kobayasiella* species. However, while 74% of the sites had more than one *Kobayasiella* species, they were present in consistently low numbers (< 2.0%). *Kobayasiella subtilissima* had the highest relative abundance at a single site at 10.7%, followed by *K. micropunctata* (6.2%), *K. parasubtilissima* (5.5%), *K. tursujuqensis* sp. nov. (5.5%), *K. pseudostauron* (2.9%) and *K. madumensis* (1.0%). *Kobayasiella subtilissima* was consistently found with *K. parasubtilissima*, *K. tursujuqensis* sp. nov. and *K. pseudostauron*. In contrast, *K. micropunctata* was associated with *K. madumensis* and *K. subtilissima*. The identifications of *K. micropunctata*, *K. tursujuqensis* sp. nov. and *K. pseudostauron* in LM are difficult due to the smaller size of the valves, but attention to central area, valve ends, and outline will be sufficient to distinguish these species. The highlighting of specific characteristics of the new species (Table 4) allows for a proper identification and a better understanding of the ecological preferences of each species.

Small *Adlafia*, *Nupela* and *Sellaphora* taxa were rare, occurring in < 49% of the sites, with *Adlafia* (2.2-48.9%) being the

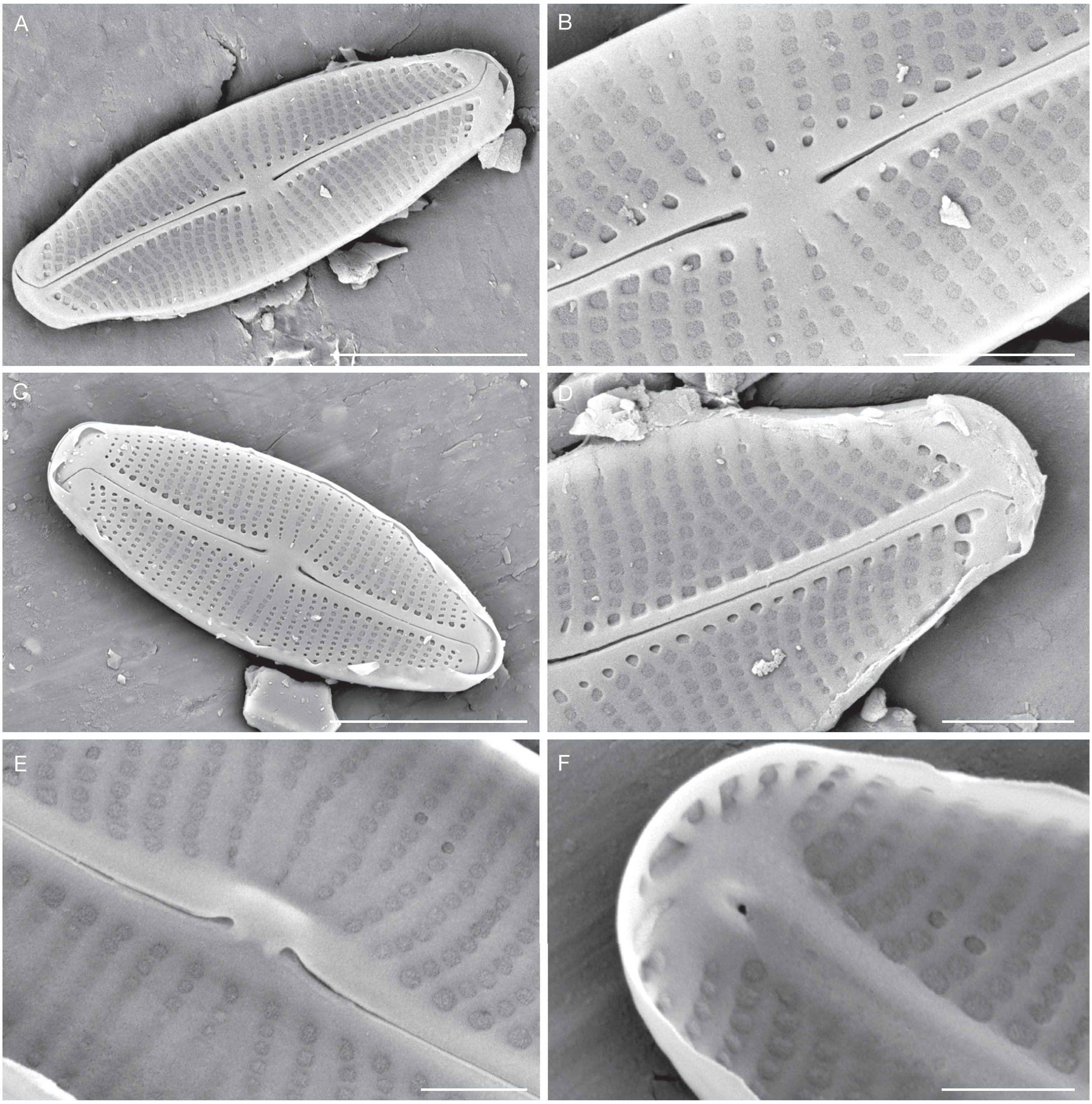

Fig. 14. — SEM images of *Sellaphora vincentiana* sp. nov.: **A**, **C**, **E**, external views of the complete valve; **B**, **F**, external view of the central area showing a linear expanded proximal fissure and recessed poroid covers over the areolae; **D**, external view of the apex with a bent fissure onto the mantle. Scale bars: A, C, 3 µm; B, D, 1 µm; E, F, 500 nm.

more common, followed by *Nupela* (29.8%) and *Sellaphora* (4.3%). *Sellaphora vincentiana* was found with *N. tenuicephala*, and all *Adlafia* taxa. Populations of *A. ossiformis* sp. nov. and *A. umiujaqensis* sp. nov. were found with low abundances of *A. bryophila* and *Kobayasiella pseudostauron*, and *K. subtilissima* was also sometimes present.

Species from the genera *Kobayasiella*, *Adlafia*, *Sellaphora* and *Nupela* are widespread across the world (Kociolek 2018). *Kobayasiella*, *Adlafia* and *Nupela* taxa are commonly found in oligotrophic conditions with low pH and low alkalinity (e.g. Siver *et al*. 2007). In contrast, *Sellaphora* taxa in the Arctic are more widely distributed across differing ecological conditions (Ponader *et al*. 2002; Antoniades *et al*. 2008; Hobbs *et al*. 2010).

Fallu *et al*. (2000) studied the diatom flora of the eastern Hudson Bay region in detail, including five sites in the western sector of what later became Tursujuq National Park. Nine of the species identified here were also recorded in their study, with eight identified as unidentified species or under a different taxon name (Table 2). Fallu *et al*. (2000) observed

Table 4. — Key distinctive traits of the newly described species.

Species	Valve outline	Position of central raphe fissures	Terminal raphe fissures	Orientation of striae	Structural formation of areolae within striae
Kobayasiella tursujuqensis sp. nov.	Small, linear to linear-lanceolate	Between mid-valve and apex	Curved, deflected, not hooked, on the secondary side of valve opening	Strongly radiate at mid-valve to strongly convergent at apices	Sometimes expanded around the central area, occluded with 4-8 rows of pores
Adlafia umiujaqensis sp. nov.	Linear-elliptic to elliptic with rounded ends	No kink-like irregularity halfway between mid-valve and apex	Curved down onto upper region of mantle	Weakly radiate at mid-valve to parallel or weakly convergent at apices, continuous from valve face to mantle	Round to rectangular, 5-7 per stria, 3-4 at apices, covered by a fine poroid velum with 8-11 circular rows of small pores
Adlafia ossiformis sp. nov.	Elliptic at mid-valve with broad capitate ends	No kink-like irregularity halfway between mid-valve and apex	Curved down onto upper region of mantle	Continuous, straight to weakly arched from valve face to mantle, more widely spaced around central area	Round to rectangular, 4-6 per stria, covered with a fine poroid velum with 8-9 circular rows of small pores
Sellaphora vincentiana sp. nov.	Linear-elliptic to elliptic with restricted rostrate ends	No kink-like irregularity halfway between mid-valve and apex	Bent down onto upper region of mantle, opening into a small circular depression	More widely spaced around central area, parallel throughout	Round to rectangular, 8-10 per stria, 3-4 at apices, covered with a recessed fine poroid velum with circular rows of small and almost indistinct pores

K. parasubtilissima (also included as the new species described here, *K. pseudostauron*) in 24 sites, which corresponds with the autecology observed of *K. parasubtilissima*. In fact, this species is recognized to be abundant in electrolyte-poor, acidic and dystrophic lakes and bogs in the northern hemisphere (Lange-Bertalot *et al.* 2017). *Kobayasiella micropunctata* was identified as *Navicula micropunctata* in Fallu *et al.* (2000). The distribution of *K. subtilissima* (synonym: *Navicula subtilissima*) in our sites agreed with the species' autecology in the literature as reaching high abundances in acidic waters.

We examined the chemical optima and tolerance ranges of each taxon to explore the ecological clustering of species groups. *Kobayasiella parasubtilissima* and *K. tursujuqensis* sp. nov. had similar ecological preferences, with lower magnesium (Mg), dissolved inorganic carbon (DIC), Sodium (Na), Silica (Si), alkalinity, pH and higher dissolved organic carbon (DOC) and total phosphorus concentrations, and their maximum relative abundances occurred in the same lake (16-H). *Kobayasiella pseudostauron* and *K. micropunctata*, associated with low DOC concentrations and high conductivity waters, had contrasting ecological preferences relative to *K. parasubtilissima* and *K. tursujuqensis* sp. nov. *Kobayasiella madumensis* and *K. subtilissima* had autecological preferences between the other *Kobayasiella* taxa. *Kobayasiella subtilissima* was closer to *K. parasubtilissima* and *K. tursujuqensis* sp. nov. with similar optimum and tolerance ranges, whereas *K. madumensis* had autecological preferences closer to *K. pseudostauron* and *K. micropunctata*.

The three *Adlafia* species examined in this study were identified in Fallu *et al.* (2000) as *Navicula bryophila*, *Navicula digitulus* Hustedt, and *Navicula ventralis* Krasske (Table 1). Considering records in Fallu *et al.* (2000) and this study, *Adlafia* spp. show a wide biogeographic distribution and ecological preferences, although they were not abundant. In northern Québec, *A. bryophila* (synonym: *Navicula bryophila*) has been identified 149 times in low abundances ranging from 0.2 to 18.5%, with a median abundance of 0.6% (Ponader *et al.* 2002; Hobbs *et al.* 2010).

Only one *Nupela* species (*N. tenuicephala*) was observed in this study, with occurrences at 15 sites, and across northern Québec it was generally present in low abundances (< 38%, median 0.5%) (Fallu *et al.* 2000; Hobbs *et al.* 2010). The ecological conditions for *Nupela tenuicephala* in northern Québec were similar between all the studies, with an association with slighty acidic waters. The genus *Nupela* is considered cosmopolitan, with many species recorded from tropical biomes and nonpolar regions (Potapova & Charles 2003; Wojtal 2009; N'Guessan *et al.* 2018; Rybak *et al.* 2019). Typical living conditions for *Nupela*, broadly speaking, are restricted by bioclimatic regions (Sala *et al.* 2014). Like *Adlafia*, the autecological range of this genus is yet to be determined. Similarly, in northern Québec, *Sellaphora* taxa to date have only been reported with voucher collections from 20 sites at < 1.5% abundance. Although many species (especially small forms) have been reported and described from around the world (García *et al.* 2020; Kochoska *et al.* 2021), *Sellaphora* distribution in the circumpolar Arctic appears to be limited.

Closer examination using electron microscopy of small diatoms that are difficult to distinguish in LM will yield new

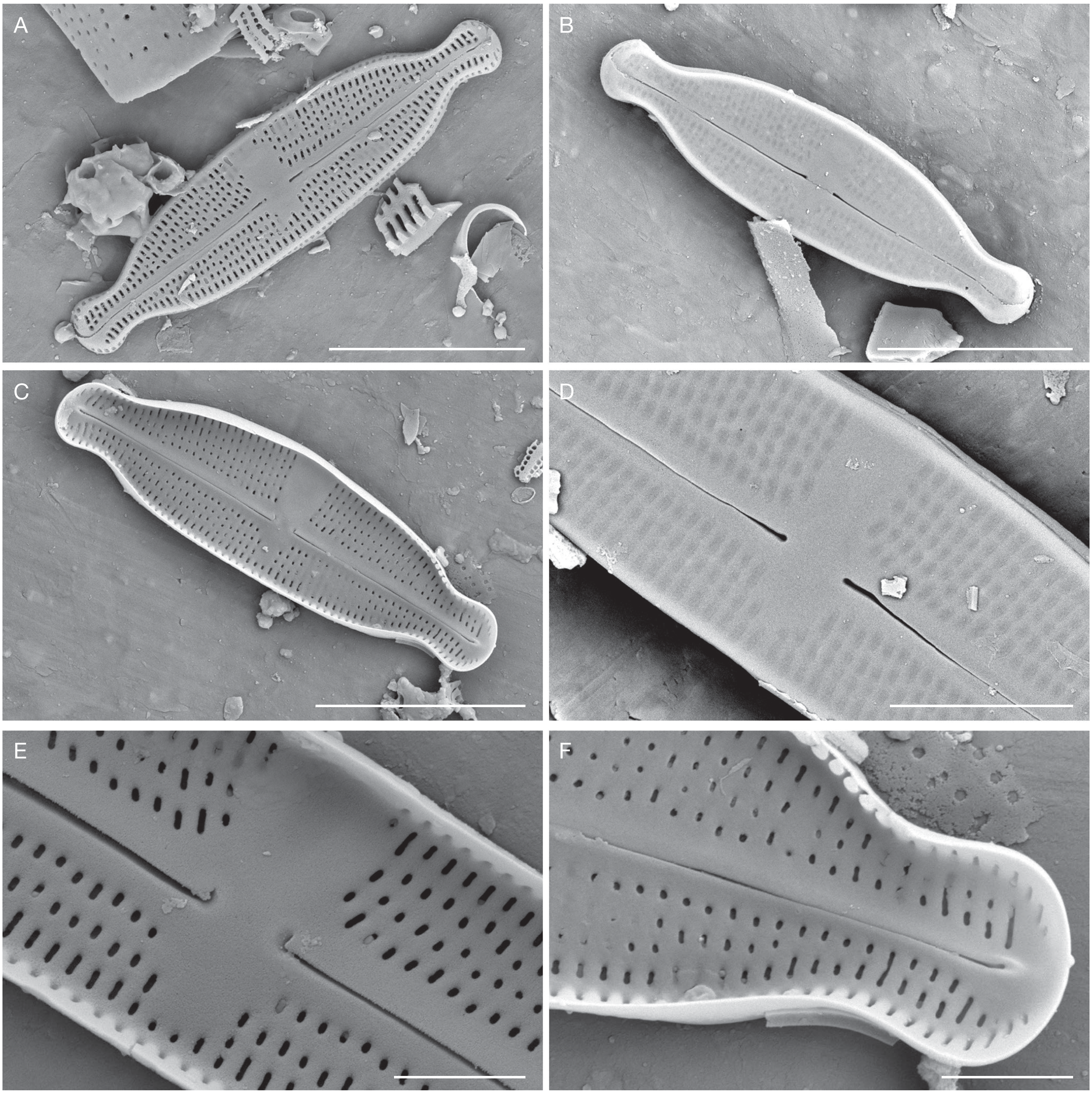

Fig. 15. — SEM images of *Nupela tenuicephala* (Hustedt) Lange-Bertalot: **A**, **B**, external views of complete valves with recessed depressions covered with multiporoid volae; **C**, internal view of the whole valve; **D**, external view of the central area showing the expanded proximal raphe fissures and multiseriate poroid covers over the areolae; **E**, internal view of the central area with bent proximal fissures; **F**, internal views of the apex, helictoglossa small and elevated. Areolae interrupted around the apex. Scale bars: A-C, 5 μm; D, 2 μm; E, F, 1 μm.

and interesting taxa, especially from the genera examined in this study. Key features observed only in SEM were needed to identify the species, and in some cases were even required to determine the genus (e.g. *Adlafia*, *Sellaphora*). Precise, morphologically based environmental assessments will require the use of high-resolution imaging for smaller species, and the identification from Nunavik of seven globally distributed species and four new species will add to the expanding environmental library of autecological data.

CONCLUSION

An examination of diatom biodiversity in lakes from Tursujuq National Park in Nunavik, Québec, Canada revealed four new species through the examination of fine-level details that were not considered in previous Arctic floral surveys. Small size, confusion in the taxonomic literature and limited population studies have hindered the identification and resolution of similar species to date. Morphological structures

TABLE 5. — Comparison of distinct morphological traits among the genera *Kobayasiella* Lange-Bertalot, *Adlafia* Moser, Lange-Bertalot & Metzeltin, *Nupela* Vyverman & Compère, and *Sellaphora* Mereschkowski.

	Genera			
	Kobayasiella	***Adlafia***	***Nupela***	***Sellaphora***
Frustule	Light to moderately silicified	–	–	–
Shape	Linear-elliptic, linear-lanceolate	–	–	–
Raphe	Straight and filiform	Linear to weakly curved	–	Slightly deflected and curved
Umbilicus	Kink-like irregularity closer to valve apices along the raphe fissure	Absent	–	–
Terminal raphe fissure	Hooks on the valve face, does not continue onto the mantle	Bends in the same direction and extends to the mantle	–	Terminates in a long helictoglossa
Areolae	–	Large and round, covered externally by a multiseriate hymen and a silica layer at the outer periphery of each areola	Elliptical in outline, externally covered with a hymen	Presence of hymen that obscures small areolae details
Striae	Alveolae-like apertures with recessed pores, arranged radially at the mid-valve changing to convergent at the Voigt fault and then extending to the apices	–	–	–
Internal structure	Narrow raised sternum, straight or T-shaped proximal ends of the raphe, small raised helictoglossa at the distal end	–	–	Central raphe ends deflected, terminal raphe fissure terminates in a long helictoglossa
Genetic affiliation	–	Distant from *Kobayasiella*, aligned with *Geissleria* and *Placoneis*	Chloroplast genetic affinity to *Pinnularia* and *Stauroneis*	Genetically associated with *Eolimna*

of direct interest in these small taxa include valve outlines, the position of the central and terminal raphe fissures, orientation of the striae, and the structural formation of the areolae within the striae (Table 5). The new taxa were found in acidic conditions (*Kobayasiella tursujuqensis* sp. nov.) and in more circumneutral waters although with weakly defined autecologies (*Adlafia ossiformis* sp. nov., *Adlafia umiujaqensis* sp. nov., *Sellaphora vincentiana* sp. nov.). A better knowledge of small naviculoid species is necessary to document the circumpolar biogeography and ecology of freshwater diatoms.

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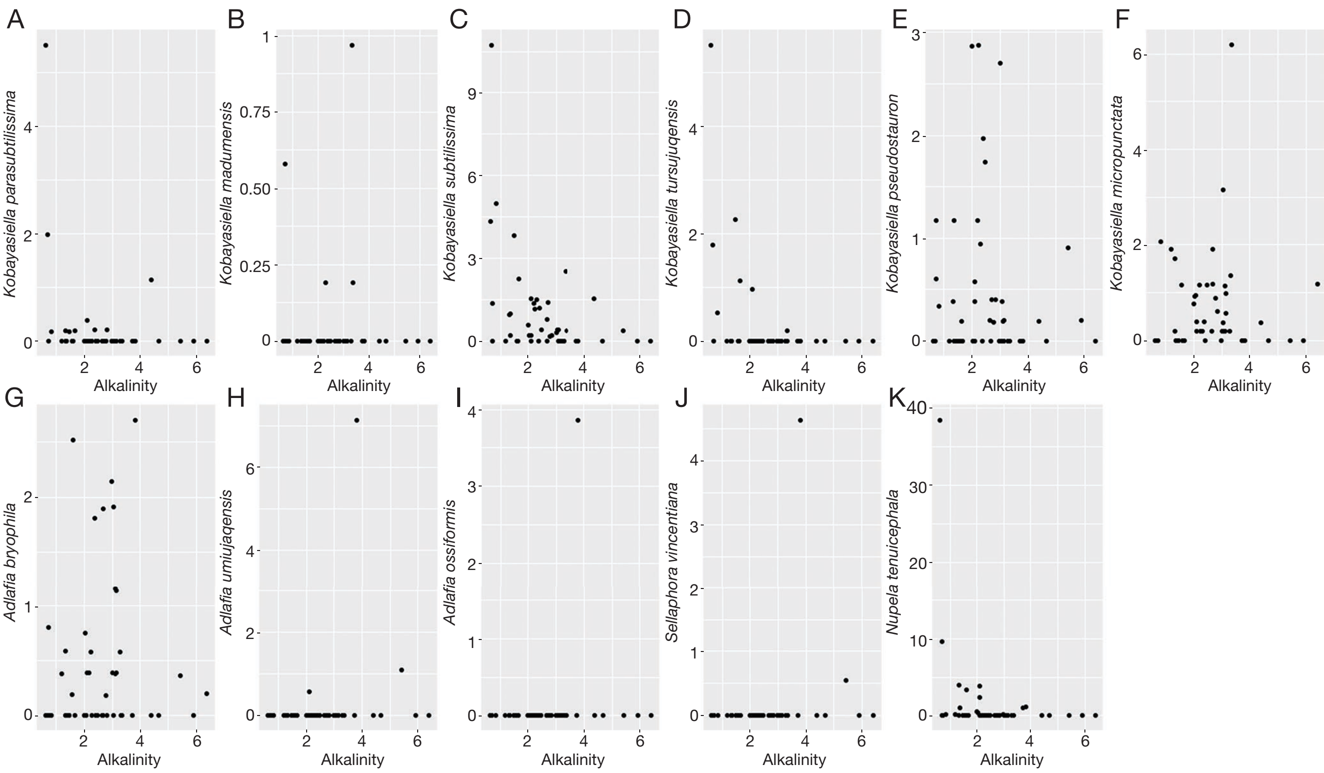
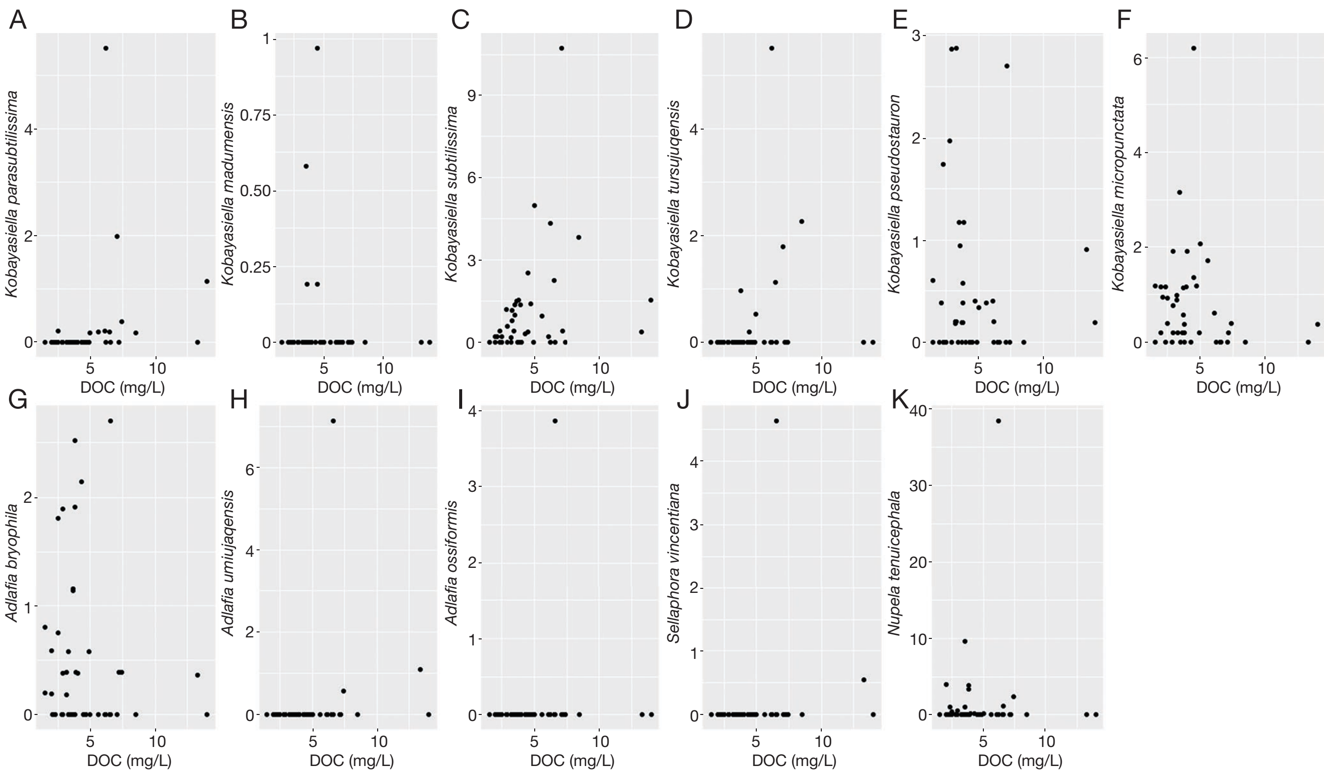
APPENDICES

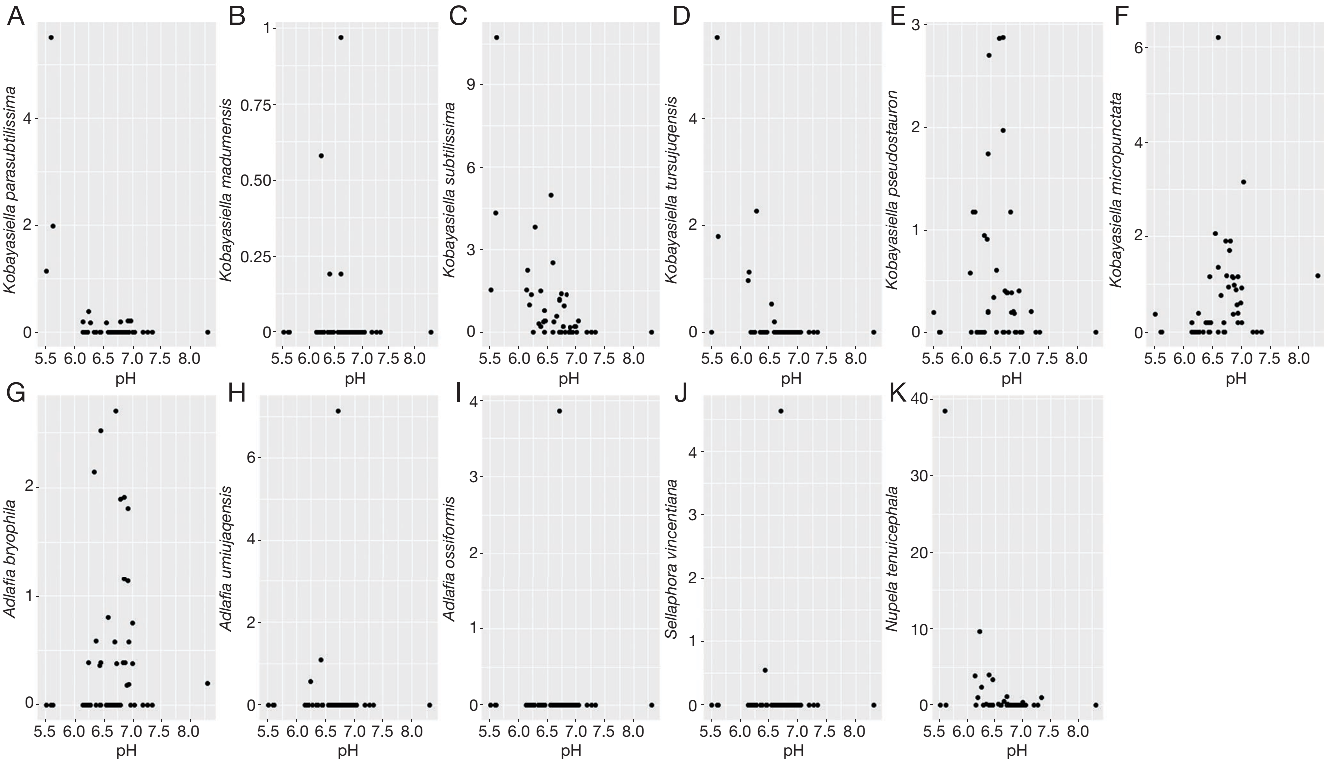
Appendix 1. — Relative abundance of species as a function of alkalinity values.



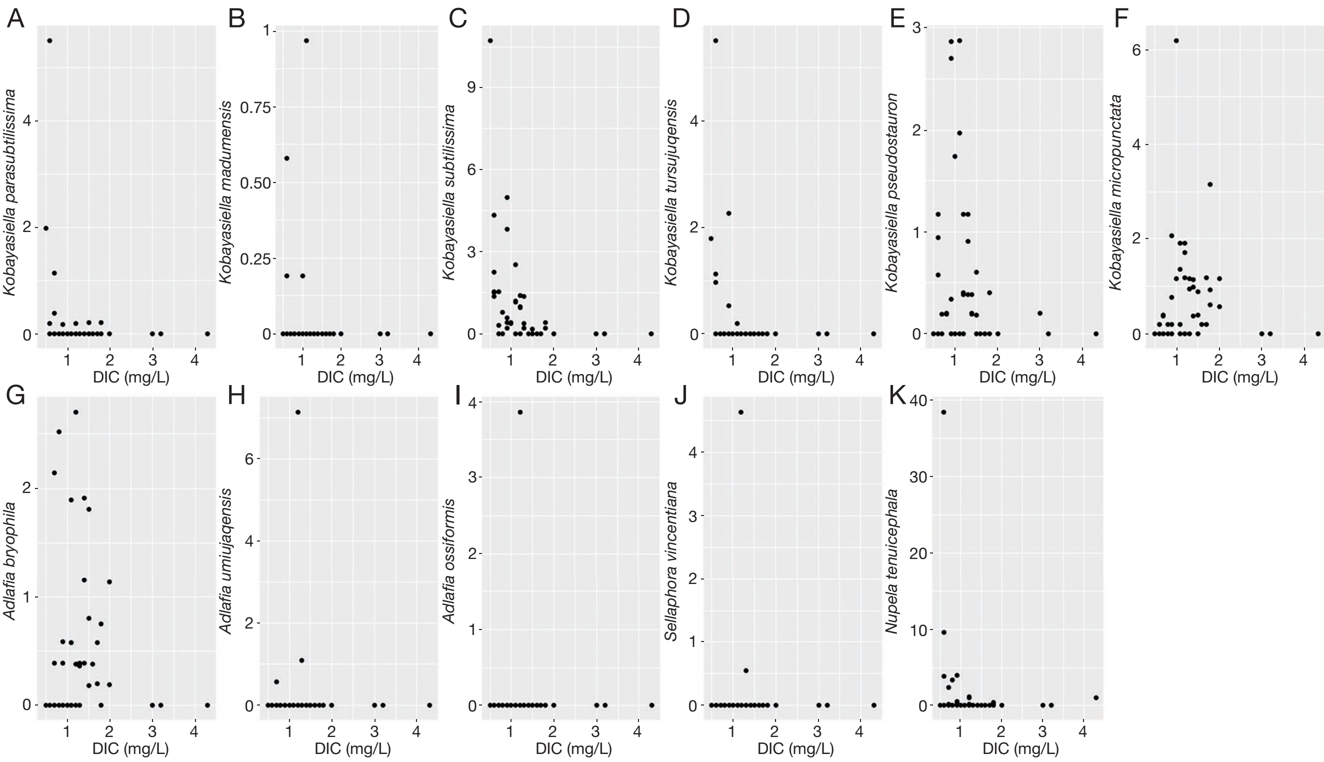
Appendix 2. — Relative abundance of species as a function of DOC concentrations.



APPENDIX 3. — Relative abundance of species as a function of pH values.



APPENDIX 4. — Relative abundance of species as a function of DIC values.



APPENDIX 5. — Relative abundance of species as a function of Mg values.