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RESEARCH PAPER

Diatom Communities in the Littoral Sediments of the Robert Island's Lakes, South Shetland Islands, Antarctica

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Abstract

The study area is situated at Robert Island, which is located in the South Shetland Islands in the northwest of the Antarctic Peninsula. The diatom samples were taken as part of the Turkish Antarctic Expedition (TAE-II) which took place between March and April 2018. The samples were collected from the surface of sediments (c. 5 cm) at a depth of approximately 20 cm, 50–100 cm from the littoral zones of an inland glacial lake (L1) and three coastal lakes (L2, L3 and L4) situated on glacier-free area on Robert Island. The main objective of this study was to reveal the diversity and the abundance of diatom communities in the littoral sediments of the lakes on Robert Island. The lakes were shallow and oligotrophic freshwater lakes, although the coastal lagoons had a high conductivity and nutrient concentration. Twenty-six diatom taxa belonging to *Achnanthes* (1), *Fragilaria* (1), *Frustulia* (1), *Gomphonema* (1), *Halamphora* (1), *Hantzschia* (1), *Hippodonta* (1), *Humidophila* (2), *Luticola* (3), *Melosira* (1), *Nitzschia* (4), *Pinnularia* (3), *Planothidium* (2), P*sammothidium* (2), *Stauroneis* (1) and *Stephanopterobia* (1) were identified in the samples from these lakes. The coastal lake L2 showed the highest richness of diatom communities among the in studied lakes, with 21 identified taxa.

Introduction

Diatoms are eukaryotic unicellular organisms that live in benthic and planktonic algal communities in a variety of aquatic and moist environments, including freshwater, marine, and terrestrial habitats. They represent a significant component of aquatic ecosystems, functioning as dominant primary producers (Jones, 1996; Akar and Şahin, 2018; Shibabaw et al., 2021) and are responsible for 20-25% of the world's total primary production (Serôdio and Lavaud, 2020). Moreover, the photosynthetic activities of these organisms are responsible for 40% of marine primary production, which may be equivalent to the contribution of all terrestrial rainforests (Serôdio and Lavaud, 2020). Diatoms exhibit significant global diversity, with a wide range of species found in nearly every environment on Earth. They represent a highly diverse group of algae, with an estimated 100,000–200,000 species (Wang et al., 2022). The composition of diatom communities is strongly influenced by local environmental factors. However, dispersal processes regulated by geographic distances also play a significant role in shaping community composition and the prevalence of endemic species (Verleyen et al., 2009). The continent of Antarctica is characterized by a high rate of endemism among diatom species (Van de Vijver et al., 2011; Kopalová et al., 2014). Antarctica continent has also been the focus of diatom research due to its extreme environmental conditions, and there is a variety of literature on the ecology and biodiversity of diatoms in different regions of Antarctica (Mazumder et al., 2012). Recent taxonomic studies of diatom communities have resulted in the identification of

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numerous new species in Antarctica (Zidarova et al., 2016). The diatom flora of South Shetland Islands, where Robert Island is located, has been studied in past decades by Kawecka and Olech (1993), Hansson and Håkansson (1994), Kawecka et al. (1998), Zidarova (2008), Kopalová and Van de Vijver (2013), Silva et al., (2019), Solak et al. (2023), Cahová and Chattová (2021). Despite the growing effort to better characterize of the diatom flora of the South Shetland Islands, the diatom flora of Robert Island remains poorly known.

The main goal of this study is to determine the biodiversity and community composition of diatoms in the littoral sediments of four lakes located on Robert Island in the South Shetland Islands, Antarctica.

Material and Methods

The South Shetland Islands (Figure 1a) were shaped by the island arc volcanism that developed from the Jurassic to the Quaternary period. The basement of the lakes was formed by the Cretaceous aged volcanic rocks. The previous studies described them mostly on Robert Island as Coppermine Formation (Smellie et al., 1984). It consists of basaltic andesite, olivine basalt (intercalated with andesite), poikilitic lapillistone, and agglomerates. Lava levels form alternations within this unit with their hard reliefs and cooling structures. The Coppermine Formation was cut by younger basaltic and basaltic andesitic dykes. All of the lakes in Robert Island

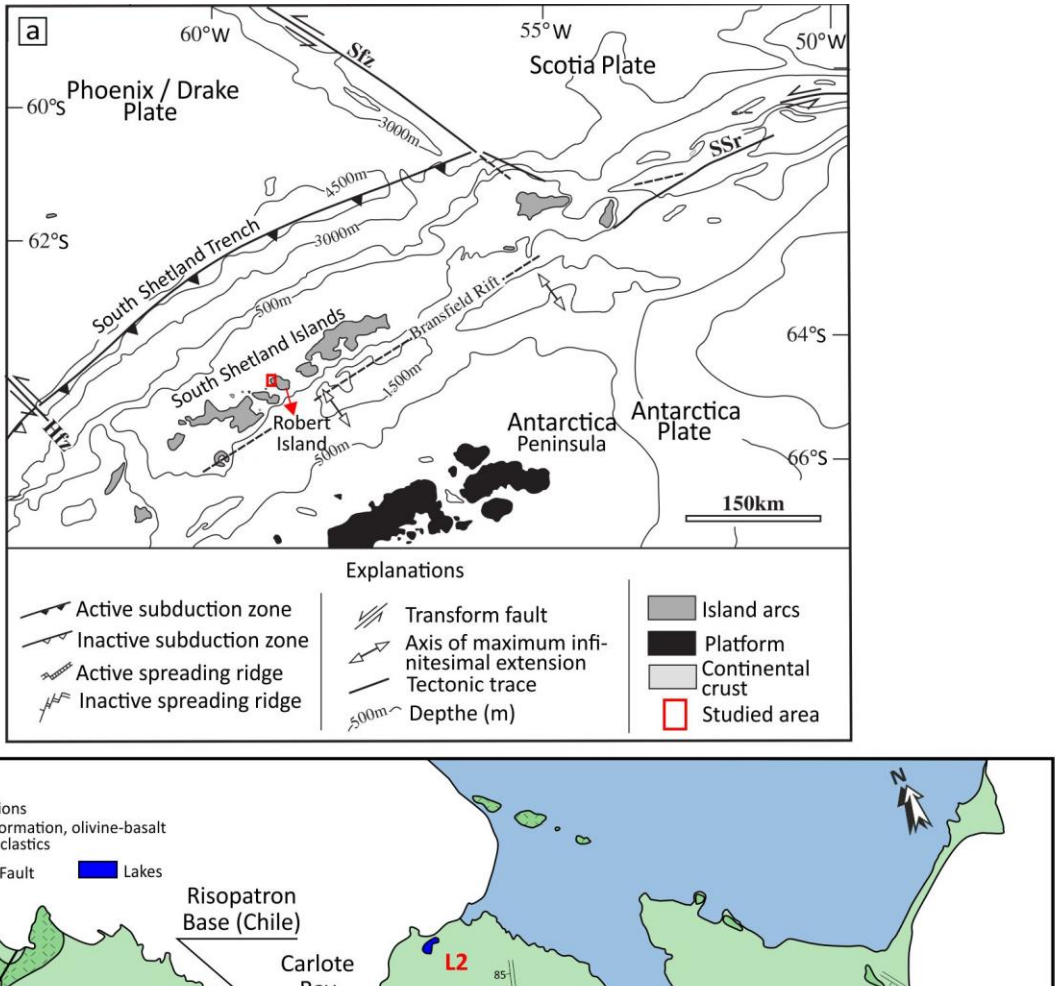

Figure 1. a- Geographic location and tectonic setting of the South Shetland Islands (modified from Machado et al., 2005), b- Geological map of Coppermine Peninsula (modified from Smellie et al., 1984 and Machado et al., 2005) and geographic location of studied lakes (Özyurt et al., 2023).

were developed on these volcanic basements (Figure 1b).

Much of the higher grounds of the Island is permanently ice-covered; however, a large portion of the coastal regions of the island, particularly the Coppermine Peninsula are ice-free. Due to its natural importance, The Coppermine Peninsula is protected as an Antarctic Specially Protected Area (ASPA-112). Robert Island hosts a diverse biota typical of the South Shetland Islands, especially for breeding and resting marine mammals such as Antarctic fur seals (*Arctocephalus gazella* Peters, 1875), southern elephant seals (*Mirounga leonina* Linnaeus, 1758) and leopard seals (*Hydrurga leptonyx* Blainville,1820). Moreover, the island is renowned for its avian population, which includes species such as the giant petrel (*Macronectes giganteus* Gmelin, 1789) and Wilson's storm petrels (*Oceanites oceanicus* Kuhl, 1820) as well as gentoo penguins (*Pygoscelis papua* Forster,1781) and chinstrap penguins (*Pygoscelis antarcticus* Forster, 1781). The vegetation of Robert Island is distinguished by a substantial moss carpet, as well as a diverse array of lichen and algae species (Colesie et al., 2022). The Coppermine Peninsula is also host to the largest continuous moss stands in the Antarctic, and it is a special environmental protection area under the Antarctic Treaty System.

Littoral diatom communities were sampled from one glacier lake and three coastal lakes in the ice-free regions of Robert Island which is located on the South Shetland Islands, Antarctica (Figure 1) during the Turkish Antarctic Expeditions-II (March-April 2018). The samples were collected from the surface of sediments (c. 5 cm) at a depth of approximately 20 cm, 50–100 cm from the littoral zones of the lakes. the physicochemical characteristics of lake water were also analyzed, with detailed methods given in Özkan (2023). Diatom samples were taken on fourteen stations from four lakes; L1 (glacier lake, Figure 1b), L2, L3 and L4 (lagoons, Figure 1b). Sediment samples for diatom analyzes were cleaned with 10% HCl and then fixed onto a lam by entellan and a lamella. The diatoms were photographed using a Leica DM 2500 P Ortholux polarizing light microscope with an oil-immersion objective at a magnification of 1600 in the Geological Engineering Laboratory of the Aksaray University Engineering Faculty. The SEM photos of the diatoms were taken using a JEOL JSM 6610 model electron microscope, in Recep Tayyip Erdoğan University Central Research Laboratory and Hitachi Regulus 8230 FE-SEM model electron microscope in Eskişehir Osmangazi University Central Research Laboratory.

All the recorded taxa were identified according to Krammer and Lange-Bertalot (1986, 1988, 1991a,b), Cremer et al. (2004), Zidarova (2008), Kopalová et al. (2009, 2012), Borromei et al. (2010), Van de Vijver et al. (2012, 2014, 2016), Pavlov et al. (2013), Kohler et al., (2015), Sterken et al. (2015), Silva (2019), Cahová and Chattová (2021). The present accepted nomenclature of the taxa is given based on Guiry and Guiry (2024).

Species abundance and distribution were calculated based on 20 microscopic fields for each slide, using a modification of the method developed by Schrader and Gersonde (1978). The classification of abundance was determined as follows: R: rare, 1-5 complete or fragmented diatoms within the twenty microscopic fields; F: few, 6-10 complete or fragmented diatoms within twenty microscopic fields; C: common, 11-15 complete or fragmented diatoms within twenty microscopic fields; A: abundant, 16-20 complete or fragmented diatoms within twenty microscopic fields.

Results and Discussion

The physicochemical parameters of the studied lakes on Robert Island were measured in situ and are shown in Table 1. The studied lakes were shallow and oligotrophic freshwater lakes. However the coastal lagoon has elevated conductivity levels and nutrient concentrations are driven by their distance to the sea.

Twenty-six diatom taxa, belonging to 16 genera were identified in total for all the samples from four lakes (Table 2). The number of diatom taxa recorded at each of the lakes (L1, L2, L3 and L4) were 20, 21, 16 and 12, respectively.

Gomphonema maritimo-antarcticum, *Hippodonta hungarica*, *Luticola multicopsis*, *Nitzschia homburgiensis*, *N. inconspicua*, *Nitzschia* sp. 1, *Pinnularia microstauron*, *P. australe*, *Psammothidium* sp. taxa were identified in all sampled lakes. Among these, *Planothidium australe* was classified as the most abundant in all the lakes sampled. In the glacier inland lake (L1), a total of 20 taxa were identified, where *N. inconspicua* (stations A, E) and *Nitzschia* sp. 2 were recorded as common species (C), while other taxa were classified as rare and few (F). With 21 taxa, L2 had the highest richness of diatoms among the sampled lakes and *Achnantes* sp., *Humidophila* sp 1., *Luticola truncata*, *Melosira* sp., *Nitzschia homburgiensis*, *Nitzschia* sp. 1, *Nitzschia* sp. 2., *P. microstauron*, *Psammothidium* sp., *Stephanopterobia* sp. were determined to be abundant (A). L3 exhibited the lowest diatom richness with a total of 12 taxa, *Humidophila* sp. 2., *N. inconspicua* and *Melosira* sp. were classifed as abundant (A) while

Table 1. Physicochemical characteristics of the lakes sampled in March-April 2018 on Robert Island during Antarctica Expedition (TAE-II). Modified from Özkan (2023)

Name	Depth (m)	Area (m^2)	Conductivity (µS/cm)	PO_4 (µg/L)	NO_2+NO_3 (µg/L)	NH_4 (µg/L)	Si (µg/L)
L1	1.5	11961	115	0.84	39.62	7.8	73.2
L2	0.3	8431	238	8.12	112.00	14.6	83
L3	0.8	6379	447	12.46	350.8	66.6	137.6
L4	1.1	11578	735	18.62	553.7	81.8	148.3

Psammothidium sp., *L. multicopsis* were classified as common (C) taxa. With the exception of *P. australe*, which was also abundant (A) in L4, all taxa were classified as rare and few according to their relative abundances.

P. australe was the most abundant diatom species in all studied lakes. The taxon (as *Achnanthes delicatula* var. *australis* Manguin 1954) was split off by Manguin based on observations made on populations from the Sub-Antarctic Kerguelen Islands (Bourrelly and Manguin, 1954). Subsequent classification of the taxon as a species was undertaken by Le Cohu (2005). *P. australe* is widespread in coastal areas of the Maritime Antarctic Region (Kopalová and Van de Vijver 2013; Kopalová et al. 2013; Sterken et al., 2015). Silva et al. (2019) detected *P. australe* in all diatom samples collected from King George, Nelson, Deception, Halfmoon and Elephant Islands in the South Shetland Islands Archipelago, Maritime Antarctica.

The diatom taxa recorded in the present study are commonly found in the larger Maritime Antarctic region (Zidarova et al. 2016). They often dominate the diatom flora of seepage areas and wet, terrestrial moss vegetation (Kopalová et al. 2012). The higher abundance of genera *Luticola*, *Psammothidium*, *Pinnularia* and *Diadesmis* might have been related to the oligotrophic nature of these lakes (Kopalova and Van de Vijver, 2013). *Gomphonema maritime-antarcticum*, *Halamphora oligotraphenta*, *Luticola multicopsis*, *Nitzschia homburgiensis*, *Pinnularia microstauron*, *Planothidium rostrolanceolatum*, *Psammothidium incognitum* and *Stauroneis latistauros* as well as taxa of the *Humidophila, Nitzschia* and *Melosira genera* were identified from King George, Nelson, Deception, Halfmoon and Elephant Islands in the South Shetland Islands (Silva et al., 2019). Moreover, *Fragilaria capucina, Hantzschia amphioxys, Luticola austroatlantica, L. multicopsis, L. truncata, N. homburgiensis, Pinnularia borealis, Stauroneis latistauros* were also observed at the at the seepages and streams on the James Ross Island and McMurdo Dry Valleys (Antarctica) (Kopalová et al., 2012; Darling, 2015; Kohler, 2015). Furthermore, *H. amphioxys, L. austroatlantica, L. multicopsis, L. truncata, N. homburgiensis, P. borealis, P. microstauron*, *Planothidium australe* and *Stauroneis latistauros* were previously been identified from the lakes and their outflows, ponds, puddles, streams and small brooks in the Livingston Island, Signy Island Beak Island and Ardley Island in maritime Antarctica (Zidarova, 2008; Sterken et al., 2015; Cahová and Chattová, 2021). Additionally, *H.amphioxys, L. multicopsis, P. borealis* were identified from the lakes in the Amery Oasis in East Antarctica (Cremer et al., 2004). The genus *Hippodonta* was represented on Robert Island by a single species, *H. hungarica*, which is widely distributed in Antarctica

Table 2. List of taxa in the glacier inland lake (L1) and coastal lakes (L2, L3, L4) with their mean relative abundances. R: rare, F: few, C: common, A: abundant

	L1					L2			L3			L4		
Taxa	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Achnanthes sp.						A		R	R			R		R
Fragilaria capucina Desmazières, Figure 2a	R													
Frustulia vulgaris (Thwaites) De Toni, Figure 2b	R				R			R						
Gomphonema maritimo-antarcticum Van de Vijver, Kopalová, Zidarova & Kociolek Figure 2c,d	R			R	F	R	R		R	R		R	R	R
Halamphora oligotraphenta (Lange-Bertalot) Levkov Figure 2e	R				R									
Hantzschia amphioxys (Ehrenberg) W.Smith, Figure 2f						R		R			R			
Hippodonta hungarica (Grunow) Lange-Bertalot, Metzeltin & Witkowski, Figure 2g	R			R	R		R			R		R	R	
Humidophila sp 1.	R				R	R	A							
Humidophila sp 2.	R		R	R						A	C			
Luticola austroatlantica Van de Vijver, Figure 2h	R					R			R					
Luticola multicopsis Van Heurck, Figure 2i				R	R	R	R	R	R	R	C	R		R
Luticola truncata Kopalová and Van de Vijver, Figure 2j						A								
Melosira sp.	F				R		A			A	R	R	R	
Nitzschia homburgiensis Lange-Bertalot, Figure 3a					R	A	A	A	R			R	F	
Nitzschia inconspicua Grunow, Figure 3b	C				C			R	R	A	R		R	
Nitzschia sp. 1	R			R	R	R	A		R		R	R	R	
Nitzschia sp. 2.	C				F	R	A	F	R				R	
Pinnularia borealis Ehrenberg, Figure 3c							F			R				
Pinnularia microstauron (Ehrenberg) Cleve, Figure 3d	R				R	A	A	F	R		R	R	R	
Pinnularia sp.								R						
Planothidium australe (Manguin) Le Cohu, Figure 3e	A	R		A	F	R	A	R	A	A	A	A	A	R
Planothidium rostrolanceolatum Van de Vijver, Kopalová & Zidarova, , Figure 3f	R	R	R	R	F	R		R						
Psammothidium incognitum (Krasske) Van de Vijver, , Figure 3g,h	R													
Psammothidium sp.	F				R	R	A	F		C		R	R	
Stauroneis latistauros Van de Vijver and Lange-Bertalot, , Figure 3i	C	R			R									
Stephanopterobia sp.							A							

(Zidarova, 2008). *Nitzschia inconspicua,* which occurred in all lakes on Robert Island, has been reported from the South Shetland Islands (Zidarova, 2008), while *Frustulia vulgaris* has been reported from the sub-Antarctic Crozet Archipelago (Van de Vijver and Beyens, 1999).

The highest diatom richness was observed in coastal lake L2 and inland glacial lake L1. In contrast the lowest diatom richness was recorded in lakes L3 and L4 (Table 2). Antarctic lakes are typically oligotrophic, and algal growth is frequently limited by a deficiency of nitrogen and phosphorus (Smith et al., 2020). Dou et al., 2013). Abundance and diversity of diatom communities in Antarctic were also impacted by the availability of water and nutrients. (Cahová and Chattová, 2021), where nutrient-rich organic material due to seabird colonies may result in dominance of few diatom taxa. Nutrient supply to inland high-altitude lakes is typically derived from local snow or glacial melt water. However, there is also evidence to suggest that highly nutrient-enriched lakes and ponds may be found in proximity to bird or seal colonies (Dieser et al., 2013). In addition, the salinity levels of coastal lakes are predominantly influenced by the input of sea spray. The activities of marine mammals and birds, specifically elephant seals and penguins, may also result in elevated nutrient concentrations within these lakes (Kopalova and Van de

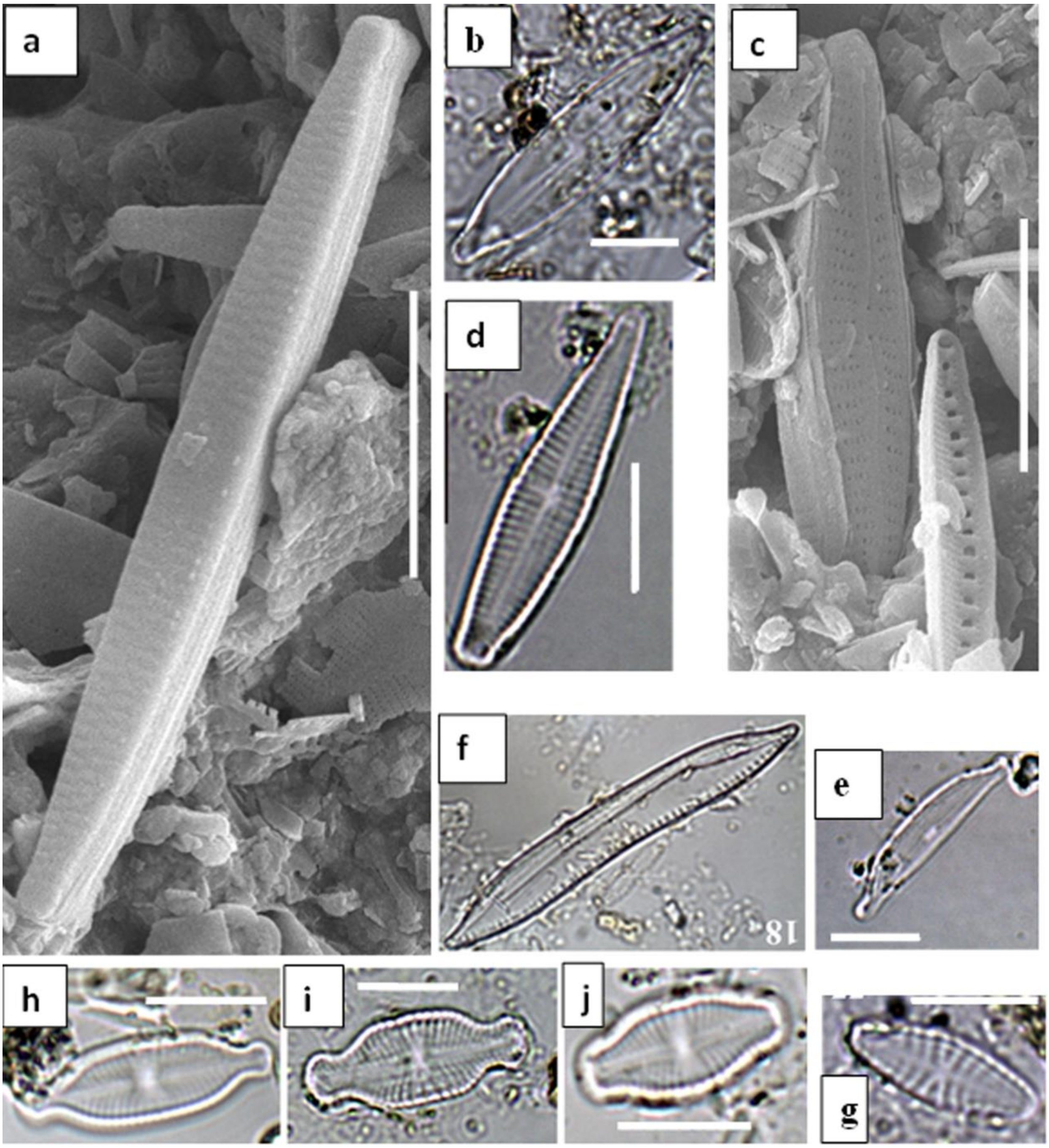

Figure 2. a. *Fragilaria capucina*, b. *Frustulia vulgaris*, c, d. *Gomphonema maritimo-antarcticum*, e. *Halamphora oligotraphenta*, f. *Hantzschia amphioxys*, g. *Hippodonta hungarica*, h. *Luticola austroatlantica*, i. *Luticola multicopsis*, j. *Luticola truncata*, Scale bar: 10 µm.

Vijver, 2013). Accordingly, the composition and abundance of diatom communities in lakes within the Antarctic are predominantly influenced by the availability of nutrients and geographical location. (Hansson and Håkansson, 1992). Furthermore, the researchers noted that diatom taxa with a restricted distribution in Antarctica were less abundant in nutrient-rich sites, in contrast to the nutrient-poor oligotrophic lakes of the central plateau, where they frequently reached high abundances (Kopalova and Van de Vijver, 2013). The coastal lakes with high nutrient concentrations (L3, L4) in the present study had the highest levels of nutrients and specific conductance (Özkan, 2023), however with the lowest diatom richness. This contradicts the expectation that more diatom richness is expected with higher nutrient availability in oligotrophic Antarctic lakes. L2 and L3 were more exposed to the prevailing winds and were much more turbid in contrast to L1 and L2, which might have resulted in less favorable conditions to diatom communities.

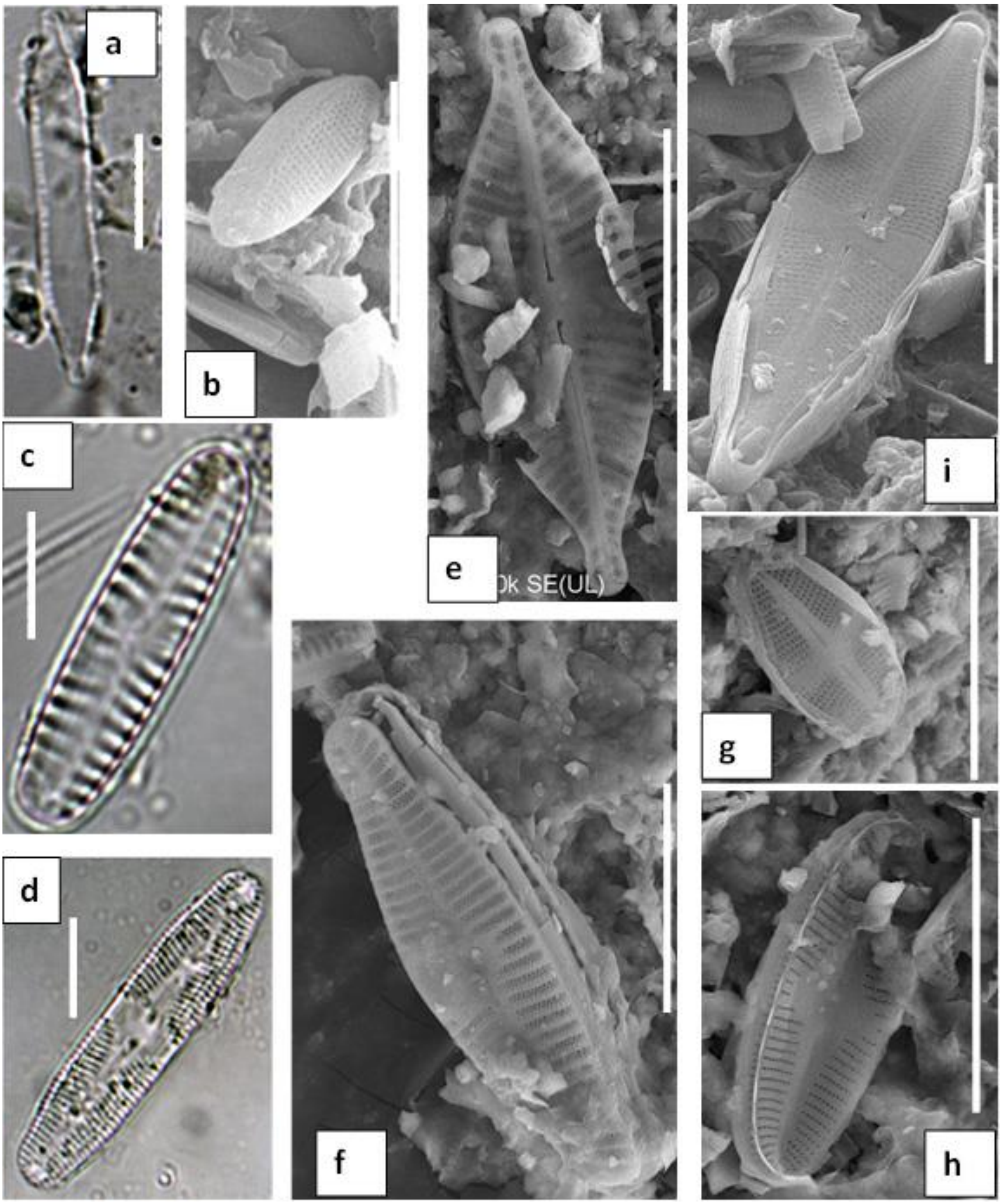

Figure 3. a. *Nitzschia homburgiensis*, b. *Nitzschia inconspicua*, c. *Pinnularia borealis*, d. *Pinnularia microstauron*, e. *Planothidium australe*, f. *Planothidium rostrolanceolatum*, g. *Psammothidium incognitum* (Raphe valve), h. *Psammothidium incognitum* (Rapheless valve), i. *Stauroneis latistauros*, Scale bar: 10 µm.

Conclusion

The diatom floras of the littoral sediments of a glacial inland lake (L1) and three coastal lakes (L2, L3, L4) on Robert Island, hosted a total of 26 taxa belonging to the genera *Achnanthes* (1), *Fragilaria* (1), *Frustulia* (1), *Gomphonema* (1), *Halamphora* (1), *Hantzschia* (1), *Hippodonta* (1), *Humidophila* (2), *Luticola* (3), *Melosira* (1), *Nitzschia* (4), *Pinnularia* (3), *Planothidium* (2), *Psammothidium* (2), *Stauroneis* (1) and *Stephanopterobia* (1). It was determined that all of the identified diatom taxa were composed of pennate forms, with the exception of Melosira sp. The most abundant taxon in all water bodies was Planothidium australe. The coastal lake L2 hosted the highest richness of diatoms with 21 taxa followed by L1 with 20, L3 with 16 and L4 with 12. We hope that this study contributes to the documentation of diatom flora of Robert Island and wider maritime Antarctica.

Ethical Statement

This article contains no studies with human or animal subjects.

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Author Contribution

First Author: Conceptualization, Writing -review and editing, Investigation, Methodology,

Second Author: Conceptualization, Writing -review and editing, Investigation, Methodology

Third Author: Data Curation, Writing -review and editing,

Fourth Author: Data Curation, Writing -review and editing,

Fifth Author: Project Administration, Data Curation, Visualization and Writing -original draft.

Conflict of Interest

The authors declare no competing interests.

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