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Posted Date: 18 December 2025

doi: 10.20944/preprints202512.1633.v1

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Article

Diatom Diversity and Its Environmental Drivers in Lakes of King George (62°S) and Horseshoe Islands (67°S) in the Maritime Antarctic

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Abstract

Diatoms are key primary producers and sensitive indicators in polar freshwater ecosystems, responding rapidly to environmental change. This study investigates diatom species richness and the influence of environmental variables in fourteen coastal lakes on King George and Horseshoe Islands in the maritime Antarctic. Water and surface sediment samples collected in 2017, 2019, and 2020 were analyzed using light and scanning electron microscopy, revealing 86 diatom species and genera across all lakes except Lake 5. King George Island exhibited higher species richness, with frequent occurrences of *Planothidium lanceolatum*, *Achnantheidium dolomiticum*, *Fragilaria capucina* and *Nitzschia hamburgiensis*. On Horseshoe Island, common taxa included *Achnanthes*, *Achnantheidium*, *Fragilaria*, *Nitzschia*, *Navicula*, and *Gomphonema*. Among the previously measured water chemistry variables, HCO₃⁻ ($\rho = 0.78$, $p = 0.005$) and K⁺ ($\rho = 0.69$, $p = 0.019$) showed the strongest positive correlations with diatom species richness. Major ions and nutrients exhibited moderate relationships with DO, salinity, and pH. In contrast, temperature and trace metals displayed weak or negligible correlations, suggesting indirect influences on diatom diversity. These findings demonstrate that diatom communities in the Maritime Antarctic lakes are highly diverse and are strongly shaped by variations in water chemistry, underscoring the ecological sensitivity of these freshwater ecosystems.

Keywords: diatoms; morphology; maritime antarctic; King George Island; Horseshoe Island; environmental drivers; lake; pond; light microscopy; scanning electron microscopy

1. Introduction

Diatoms (Bacillariophyta) are a major group of microalgae in aquatic systems, dominating the water columns in rivers and oceans. As primary producers, diatoms are responsible for approximately 25% of global and 50% of marine primary production, which exceeds the amount of oxygen produced by all rainforests [1]. Through this production, diatoms contribute to carbon fixation, holding around 45% of marine CO₂ [2]. Moreover, diatoms provide the main dietary source for aquatic feeders, thereby representing a major component of aquatic food webs, particularly in the Antarctic polar regions. Considering this key role, the identification of diatoms in Antarctic lakes is important for understanding how these communities will respond to extreme conditions and the multiple impacts of stressors such as warming, climate change and human-caused stressors.

In Antarctica, diatoms are very common and important primary producers in both marine and freshwater systems where they participate in nutrient cycling and food webs. Phytoplankton productivity is also important for regulating atmospheric carbon and methane as the lakes on King George Island were found to be a net carbon dioxide sink on an annual basis [3]. High variability of bacterial communities among different lakes suggested strong spatial differences among lakes in the Maritime Antarctic [4]. Previous studies have documented different diatom species in some regions,

especially on King George Island and other South Shetland Islands [5–7]. These studies have indicated that environmental factors such as temperature, salinity, pH, nutrients, and even exposure to darkness and glaciers are strong determinants of diatom composition [8–10]. Changes in temperature and salinity may affect the biochemical properties of some diatom species such as *Nitzschia lecontei* [11]. Similarly, metal bioavailability is also important because metals play key roles as cofactors in many metabolic reactions, thereby affecting growth rates [12]. For instance, manganese (Mn) and iron (Fe) are essential for enzymes used in photosynthesis and detoxification mechanisms, while molybdenum (Mo) is a key element in the nitrogen cycle [13–15]. Additionally, cobalt (Co), copper (Cu) and zinc (Zn^{+2}) affect growth of the marine diatoms, highlighting how metal co-limitation is crucial for enzyme catalysis, protein structure and metabolism, especially in high-nutrient low-chlorophyll (HNLC) regions as Fe is a limiting-factor [16,17]. In addition to metal requirements, macronutrients, micronutrients, and ions are essential for algal growth [18]. For instance, diatoms require silica (Si) for cell wall formation, nitrogen (N) and phosphorus (P) for biochemical synthesis, sodium (Na^+) for cell division, and calcium (Ca^{+2}), magnesium (Mg^{+2}), sulfate (SO_4^{-2}), nitrate (NO_3^-), potassium (K^+), and bicarbonate (HCO_3^-) for other physiological processes [19]. A recent study showed that chlorophyll-a (Chl-a) concentrations have a strong correlation with ammonium (NH_4^+) and NO_3^- in the Maritime Antarctic, suggesting that nutrients, as well as key cations and anions, play an important role in phytoplankton growth [18].

On the other hand, it has been shown that six benthic diatom species from the Antarctic Peninsula can acclimate to fluctuating temperature, salinity and light levels broader than their actual conditions, suggesting high flexibility in coping with environmental change [10]. Together, these studies emphasize that Antarctic diatoms are strongly influenced by changing of environmental conditions, yet they also exhibit some plasticity to cope with ongoing and possible future stressors.

Despite all these previous studies, our knowledge of Antarctic freshwater diatom diversity remains incomplete. Many lakes and ponds across the Antarctic region have yet to be studied systematically. Although some new diatom species have been identified over the past few decades through morphological or molecular approaches [5,6,20,21], most available records are still limited. While molecular methods such as metabarcoding are increasingly applied to samples to improve taxonomic knowledge [4], there are still some debates regarding the preservation of deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA) in remote field expeditions and ongoing isolation and sequencing procedures. Consequently, morphological identification by light microscopy (LM) and scanning electron microscopy (SEM) seems to be more reliable and applicable approach for characterization of diatom communities in these harsh environments. Therefore, to contribute to our current knowledge gaps about diatom diversity, we examined the diatom species of lakes and ponds from King George Island (62°S) in the South Shetland Islands and Horseshoe Island (67°S) further south on the Antarctic Peninsula. Using light and scanning electron microscopy, we examined diatom distribution and richness and discussed how physicochemical parameters and key nutrients, metals and ions can affect diatom variability across sampling sites, also considering possible future climate effects.

2. Materials and Methods

2.1. Study Site

Sampling of water, filters and sediments from lakes and ponds in the Maritime Antarctic was performed in three field campaigns; first in February–March 2017, second in January 2019 on King George Island and third in February 2020 on Horseshoe Island (Table 1).

Table 1. The studied lakes and ponds from King George and Horseshoe Islands with geographic information.

Sites	Other Name	Abbreviation	Latitude	Longitude	Sampling Date	Sample Type
King George Island - Fildes Peninsula						
Lake 1	Uruguay	L1	-62.1853	-58.9118	25 Feb 2017 14 Jan 2019	Water, filter

Lake 2	Kitiesh	L2	-62.1936	-58.9664	19 Feb 2017 17 Jan 2019	Water, sediment, filter
Lake 3	-	L3	-62.2010	-58.9729	02 Mar 2017	Water, sediment
Lake 4	Langer	L4	-62.2050	-58.9665	02 Mar 2017 09 Jan 2019	Water, sediment
Lake 5	West	L5	-62.2172	-58.9660	02 Mar 2017	Water, sediment
Lake 6	-	L6	-62.2210	-58.9590	02 Mar 2017	Water, sediment
Pond 1	-	P1	-62.1893	-58.9295	25 Feb 2017	Water, sediment
Pond 2	-	P2	-62.1920	-58.9417	25 Feb 2017	Water, sediment
			-62.2210	-58.9590	09 Jan 2019	
Pond 3	-	P3	-62.1944	-58.9486	25 Feb 2017	Water, sediment
Organic Pond 1	-	OP1	-62.1887	-58.9242	25 Feb 2017	Water, sediment
King George Island – Ardley Island						
Organic Pond 2	-	OP2	-62.2104	-58.9410	02 Mar 2017 16 Jan 2019	Water, sediment, filter
Horseshoe Island						
Horseshoe 1	-	HS1	-67.22486	-67.82847	21 Feb 2020	Water, sediment, filter
Horseshoe 2	-	HS2	-67.22252	-67.82569	21 Feb 2020	Water, sediment, filter
Skua Lake	-	SK	-67.18066	-67.48444	27 Feb 2020	Water, sediment, filter

Samples were collected from nine lakes (L1-L6, HS1, HS2, SK), three ponds (P1-P3) and two organic ponds (OP1, OP2) (Figure 1, Table 1). Only OP2 was located on Ardley Island section of King George, while the others were from the Fildes Peninsula (Figure 1a,f). The sampling locations were studied previously to understand methane and carbon dioxide cycles and also lithological controls on lake water chemistry (Olgun et al., 2024; Thalasso et al., 2022). In the second campaign, water and filter samples were taken from five of these lakes including Uruguay (L1), Kitiesh (L2), L4, P1, OP2 (Table 1), while no sediment samples were taken in 2019. The third campaign in 2020 on Horseshoe Island (Figure 1b,) was done as part of the Turkish Antarctic Expedition (TAE) and water, filter and sediment samples were collected from Horseshoe-1 (HS1), Horseshoe-2 (HS2) and Skua Lake (SK) (Figure 1e,h,g,i).

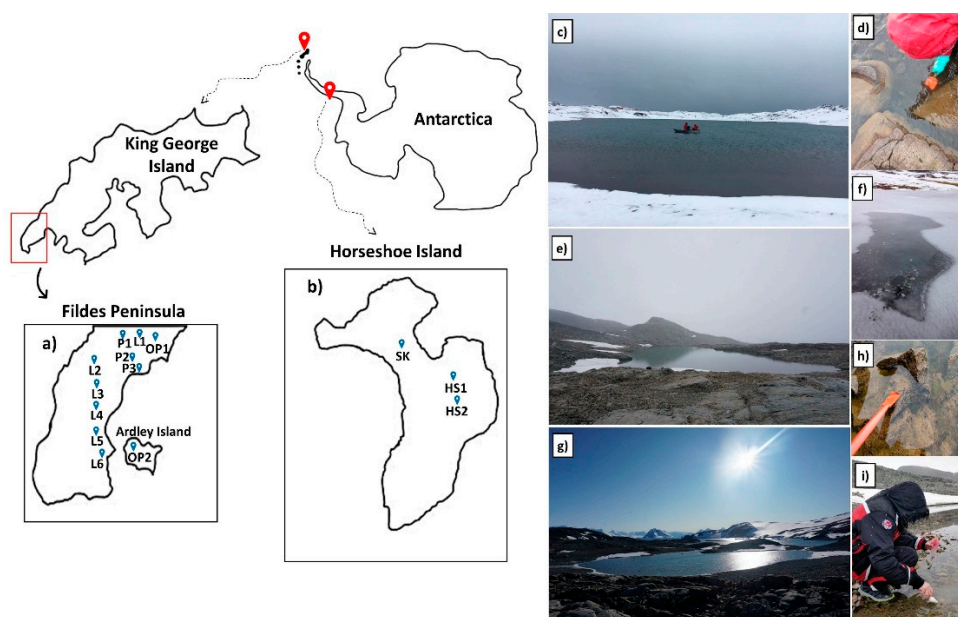


Figure 1. Representative map showing the locations of studied lakes and ponds in the (a) Fildes Peninsula and Ardley Islands on King George Island and (b) Horseshoe Island in the Maritime Antarctic in the western coastal region on Antarctic Peninsula. Field photographs showing (c) sampling with a small boat in Kitiesh Lake (L2), (d) sediment sampling from littoral zone of Kitiesh Lake, (e) and (h) sampling and a view of Horseshoe Lake 1

(HS1) (f) Organic Pond OP2 in Ardley Island in King George with a thin ice cover and the hole opened for sampling, and (g) and (i) view and sampling of Skua Lake (SK) in Horseshoe Island. .

2.2. Sampling

Samples from L2 on King George Island were collected from a single location at the center of the lake (-12 m water depth) using a small boat (Figure 1c). The L2 water sample was collected with a 2.2 L Van Dorn water sampler and the sediment sample with a sediment grab (Figure 1d). Due to harsh weather conditions, samples from other lakes were collected from a single sampling location in the littoral zone of the lakes and ponds. No sediment sample was taken from L1 in either 2017 or 2019. All sediment samples were stored in plastic bags and kept cool at a temperature of +4°C.

100 mL of water samples were used for morphological species identification. To preserve the samples, 0.5 mL of Merck® Lugol's iodine solution was added per 50 mL of sample. The samples were then covered with aluminum foil to protect from sunlight and were stored in the refrigerator +4°C.

Filter samples were collected by filtering 2370 mL of surface water from L1, 4870 mL from L2, 1500 mL from OP2, 200 mL from HS1 and HS2 and 150 mL of SK through Whatman® polycarbonate (PC) filters with 0.22 µm pore size and 47 mm diameter. Filter sample of L1 was used for phytoplankton species determination in SEM analyses as there were no sediment samples from L1. After the filtration process, the filters were carefully folded and placed in an aluminum foil and then stored at a temperature of -20°C.

Water parameters including pH, dissolved oxygen (DO), temperature, conductivity, salinity and total dissolved solids (TDS) were measured in six lakes and five ponds on King George Island in 2017 using a multiparameter probe (HI 9828, Hanna Instruments, Mexico) (Table 2). Chl-a concentrations were measured using an Ultraviolet-visible (UV-Vis) spectrophotometry in the Chilean Escudero Station (Table 2) (Thalasso et al., 2022). Oxidation-reduction potentials (ORP) of five of these lakes on King George were measured in 2019 (Table 2). The measured parameters were not identical in each lake or each year, as the samplings were done in different campaigns. Indicated metal, nutrient and ion concentrations in Table 2 are based on ion chromatography and inductively coupled plasma mass spectrometer (ICP-MS) data obtained in a previous study (Olgun et al., 2024).

Table 2. Physicochemical parameters of lakes and ponds in King George and Horseshoe Islands. Water parameters for 2017 sampling were based on [3] and key nutrient, ions and metals concentrations were based on ion chromatography and ICP-MS measurements conducted in [18]. DO: Dissolved Oxygen, Temp.: Temperature, Con.: Conductivity, Salin.: Salinity, TDS: Total Dissolved Solids, Chl-a: Chlorophyll a, ORP: Oxidation Reduction Potential. NA: not available.

Sites	pH	DO (%)	Tem. (°C)	Con. (µS cm ⁻¹)	Salin. (g/l)	TDS (mg L ⁻¹)	Chl-a (µg L ⁻¹)	ORP (mV)	Key Nutrients (µg/L)	Key Ions (µg/L)	Key Metals (µg/L)	Diatom Species Richness
L1 (2017)	7.4	87	5.2	95	0.04	48	0.2	NA	NO ₃ ⁻ : 0.06	HCO ₃ ⁻ : 15.50	Fe: 39.54	4
									PO ₄ ³⁻ : <0.001	Mg: 1.00	Mn: <1	
(2019)	9.2	100	4.8	122	0.06	61	NA	121	SO ₄ ²⁻ : 2.77	Na: 12.44	Zn: 5.02	NA
									Si: 8.57	K: 0.27	Cu: 14.76	
L2 (2017)	7.2	88	2.5	208	0.10	104	1.3	NA	P: 1.53	Ca: 0.90	Ni: <1	19
									NO ₃ ⁻ : 0.01	HCO ₃ ⁻ : 20.50	Fe: 36.20	
(2019)	11.6	101	5.1	176	0.08	NA	NA	NA	PO ₄ ³⁻ : <0.001	Mg: 2.17	Mn: <1	NA
									SO ₄ ²⁻ : 6.61	Na: 16.73	Zn: 1.71	
L3	8.5	97	0.8	115	0.05	58	0.3	NA	Si: 6.76	K: 0.60	Cu: 14.31	14
									P: <1	Ca: 4.88	Ni: <1	
(2019)	11.6	101	5.1	176	0.08	NA	NA	NA	NO ₃ ⁻ : 0.03	HCO ₃ ⁻ : 19.50	Fe: 52.50	14
									PO ₄ ³⁻ : <0.001	Mg: 2.08	Mn: <1	
L3	8.5	97	0.8	115	0.05	58	0.3	NA	SO ₄ ²⁻ : 5.27	Na: 14.78	Zn: 3.24	14
									Si: 5.93	K: 0.44	Cu: 13.98	

									P: <1	Ca: 5.15	Ni: <1	
L4	8.0	89	1.7	206	0.10	103	0.3	NA	NO ₃ ⁻ : 0.11	HCO ₃ ⁻ : 31.00	Fe: 51.62	31
(2017)									PO ₄ ³⁻ : <0.001	Mg: 2.15	Mn: <1	
									SO ₄ ²⁻ : 45.35	Na: 25.12	Zn: 6.06	
									Si: 10.56	K: 1.14	Cu: 13.27	
									P: 2.21	Ca: 14.61	Ni: 1.85	
(2019)	9.4	112	8.9	313	0.15	156	NA	141	NA	NA	NA	
L5	7.8	84	2.0	75	0.03	38	0.5	NA	NO ₃ ⁻ : 0.08	HCO ₃ ⁻ : 18.50	Fe: 39.23	0
									PO ₄ ³⁻ : <0.001	Mg: 1.43	Mn: <1	
									SO ₄ ²⁻ : 2.03	Na: 9.97	Zn: 1.02	
									Si: 7.25	K: 0.29	Cu: 13.72	
									P: <1	Ca: 3.47	Ni: <1	
L6	7.9	97	1.5	111	0.05	56	1.4	NA	NO ₃ ⁻ : 0.21	HCO ₃ ⁻ : 31.50	Fe: 40.82	26
									PO ₄ ³⁻ : <0.001	Mg: 2.25	Mn: <1	
									SO ₄ ²⁻ : 3.19	Na: 14.55	Zn: 0.99	
									Si: 11.21	K: 0.62	Cu: 13.52	
									P: <1	Ca: 5.36	Ni: <1	
P1	8.8	100	5.5	68	0.03	34	0.7	NA	NO ₃ ⁻ : <0.001	HCO ₃ ⁻ : 19.50	Fe: 39.39	19
									PO ₄ ³⁻ : <0.001	Mg: 1.34	Mn: 1.33	
									SO ₄ ²⁻ : 2.58	Na: 10.33	Zn: 1.52	
									Si: 7.00	K: 0.30	Cu: 16.37	
									P: <1	Ca: 1.62	Ni: <1	
P2	9.1	100	3.2	37	0.02	18	0.5	NA	NO ₃ ⁻ : 0.02	HCO ₃ ⁻ : 16.50	Fe: 40.22	22
(2017)									PO ₄ ³⁻ : <0.001	Mg: 0.57	Mn: <1	
									SO ₄ ²⁻ : 1.16	Na: 6.04	Zn: 4.02	
									Si: 5.05	K: 0.21	Cu: 14.86	
									P: 1.38	Ca: 0.75	Ni: <1	
(2019)	9.1	99	7.1	103	0.05	51	NA	145	NA	NA	NA	
P3	8.4	93	5.2	100	0.05	50	0.7	NA	NO ₃ ⁻ : 0.47	HCO ₃ ⁻ : 23.50	Fe: 65.96	25
									PO ₄ ³⁻ : <0.001	Mg: 1.86	Mn: 3.69	
									SO ₄ ²⁻ : 3.11	Na: 15.11	Zn: 14.41	
									Si: 10.15	K: 0.49	Cu: 15.34	
									P: 6.34	Ca: 3.22	Ni: <1	
OP1	8.5	98	5.1	57	0.03	28	2.6	NA	NO ₃ ⁻ : 0.01	HCO ₃ ⁻ : 21.50	Fe: 183.60	18
									PO ₄ ³⁻ : <0.001	Mg: 0.97	Mn: 9.88	
									SO ₄ ²⁻ : 2.27	Na: 9.62	Zn: 9.70	
									Si: 12.76	K: 0.25	Cu: 42.74	
									P: 9.08	Ca: 1.36	Ni: <1	
OP2	8.4	100	0.9	256	0.12	128	6.9	NA	NO ₃ ⁻ : 3.12	HCO ₃ ⁻ : 34.50	Fe: 100.88	28
(2017)									PO ₄ ³⁻ : <0.001	Mg: 5.84	Mn: 22.62	
									SO ₄ ²⁻ : 9.86	Na: 29.97	Zn: 1.37	
									Si: 17.80	K: 1.87	Cu: 13.96	
									P: 76.15	Ca: 9.25	Ni: 1.29	
(2019)	9.3	108	9.2	112	0.05	56	NA	103	NA	NA	NA	
HS1	8.0	95	2.8	108	NA	NA	NA	NA	NA	NA	NA	2
HS2	8.1	88	1.1	122	NA	NA	NA	NA	NA	NA	NA	4
SK	7.6	87	2.3	158	NA	NA	NA	NA	NA	NA	NA	3

2.3. Morphological Analyses with LM and SEM

Each diatom group was assigned to one of the diatom taxa based on its valve symmetry, septa, striae, raphe system, and valve shapes. The presence or absence of raphe and its position was the first step for distinguishing between different diatom species. Further identification of raphid diatoms was performed by examining the characteristics of the raphe itself, such as its form, curvature, and number of striae. The position of the raphe on the valve can also vary from species to species. For example, it may occur at the edges, on the side or offset from the center of the valve. In cases where a raphe was not visible, the septa were used for identification. However, a morphology-based identification approach alone may be insufficient for some species because of high morphological similarities and some blurred microscopic images.

For LM analysis, both water and sediment samples were used. For the sediment samples, one gram of bulk wet sediment was diluted in 50 ml of distilled water and vortexed for 45 seconds at 1600 rpm. No acid digestion using hydrogen peroxide or hydrochloric acid was applied to samples in order to avoid the loss of additional information belonging to other microorganisms such as coccolithophorids, if present. The slides were covered with Merck® immersion oil and examined under 100x objective lens. An Ivymen System light microscope equipped with a Zeiss Plan-Apochromat 100x immersion lens was used. The images were generated with a Canon EOS 500D digital camera equipped with Canon EOS Utility software (Canon Inc., Tokyo, Japan).

SEM image analyses of diatom frustules were conducted with sediment samples, as the number of frustules in the water samples was insufficient and diatom abundance was very low. For L1, the filter collected in 2019 was used, since there were no available sediment samples from this lake. For SEM analysis, one gram of bulk sediment was diluted in 50 mL distilled water and vortexed at 1600 rpm for 45 seconds. The sediment suspension was then filtered through a Whatman® polycarbonate filter (0.22 µm pore size). Filters were placed in Petri dishes and dried for five hours in an incubator at 70 °C before SEM examination. A small portion of each filter (approximately one centimeter square) was cut, mounted on aluminum stubs, and coated with gold. SEM analyses were conducted using a Zeiss EVO 10 scanning electron microscope. The relative abundance of each diatom taxa observed in the sediment samples (except for L1) was categorized as follows: very rare (vr): 1-5 shells, rare (r): 5-10 shells, frequent (f): 10-30 shells, and common (c) >30 shells (Table S1).

3. Results

This A total of 86 diatom species and genera were recorded from King George and Horseshoe Islands. A summary of the diatom species encountered in each lake is listed with their relative abundances in Supplementary Table (Table S1). Representative LM and SEM images showing the morphology of the recorded diatoms are presented in Figure 3. The most frequently observed species across the studied lakes were *Planothidium lanceolatum*, *Achnantheidium dolomiticum*, *Fragilaria capucina*, *Nitzschia hamburgiensis*, *Planothidium delicatulum*, *Pinnularia brebissonii* and *Craticula pseudocitrus* (Figure 2).

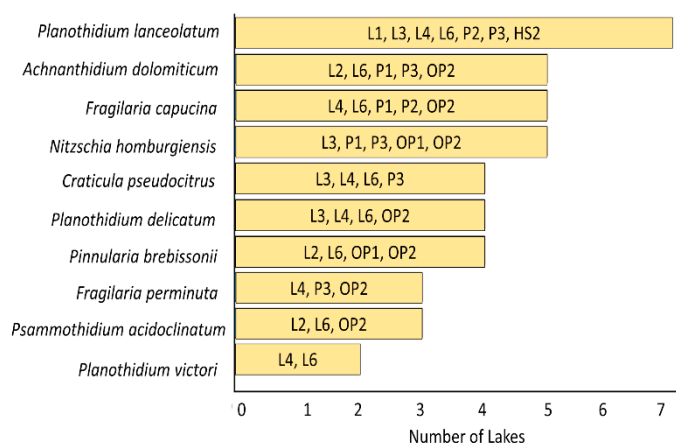


Figure 2. The ten most widespread diatom species identified in lakes and ponds of King George and Horseshoe Islands in the Maritime Antarctic.

The sizes of diatom valves varied, ranging from approximately 10 µm to 40 µm in length and from 2 µm to 15 µm in width. *Pinnularia divergens* and *Achnanthes sp.* were the largest species encountered, with approximately 10-15 µm in length (Figure 3, pic. 1, 43). In contrast, *Achnantheidium cf. dolomiticum* and *Diadesmis sp.* species were the smallest, ranging from 10 µm in length (Figure 3, pic. 19, 39). Most identified taxa were pennate diatoms, except for a few centric diatoms found in L1 and L6 in Fildes Peninsula, and in OP2 on Ardley Island (Figure 3, pic. 84).



Figure 3. Examples of diatom species in King George and Horseshoe Islands. 1. *Pinnularia divergens* in L4 2. *Pinnularia subcapitata* var. *subrostrata* in OP2 3. *Pinnularia* cf. *rhombarea* in OP1 4. *Pinnularia microstauron* var. *elongata* in P3 5. *Pinnularia subsolaris* in OP1 6. *Pinnularia brebissonii* in LM in OP1 and SEM in L6 7. *Pinnularia* cf. *quadratarea* in P2 8. *Pinnularia* sp. in P2 9. *Fragilaria* cf. *capucina* in P1 10. *Fragilaria* sp. in OP2 11. *Pinnularia borealis* in OP1 12. *Pinnularia* cf. *subantarctica* in OP2 13. *Fragilaria* cf. *nanana* in P1 14. *Fragilaria* cf. *rumpens* in OP1 15. *Fragilaria* cf. *fragilarioides* in P2 16. *Fragilaria cochabambina* in P3 17. *Fragilaria capucina* in OP2 18. *Fragilaria* sp. in L3 19. *Achnanthis* cf. *dolomiticum* in OP2 20. *Achnanthis* cf. *minutissimum* in P2 21. *Achnanthis nanum* in L2 22. *Achnanthis* cf. *australexiguum* in L2 23. *Achnanthis* spp. in P1 24. *Achnanthis* cf. *reimeri* in L6 25. *Achnanthis* sp. in OP2 26. *Humidophilia* sp. in OP2 27. *Humidophilia arcuata* var. *parallela* in P2 and P3 28. *Planothidium lanceolatum* in P2 29. *Planothidium* cf. *frequentissimum* in L4 30. *Planothidium delicatulum* in L4 31. *Planothidium* cf. *subantarcticum* in L3 32. *Planothidium biporum* in L3 33. *Planothidium cryptolanceolatum* in P3 34. *Planothidium victorii* in L4 35. *Planothidium incuriatum* in L4 36. *Planothidium* sp. in L6 37. *Diadesmis tabellariaeformis* in P3 38. *Diadesmis* cf. *faurei* in P3 39. *Diadesmis* sp. in P1 40. *Craticula* spp. in OP2 41. *Craticula pseudocitrus* in L6 42. *Achnanthes* cf. *sinaensis* in P1 43. *Achnanthes* sp. in L4.

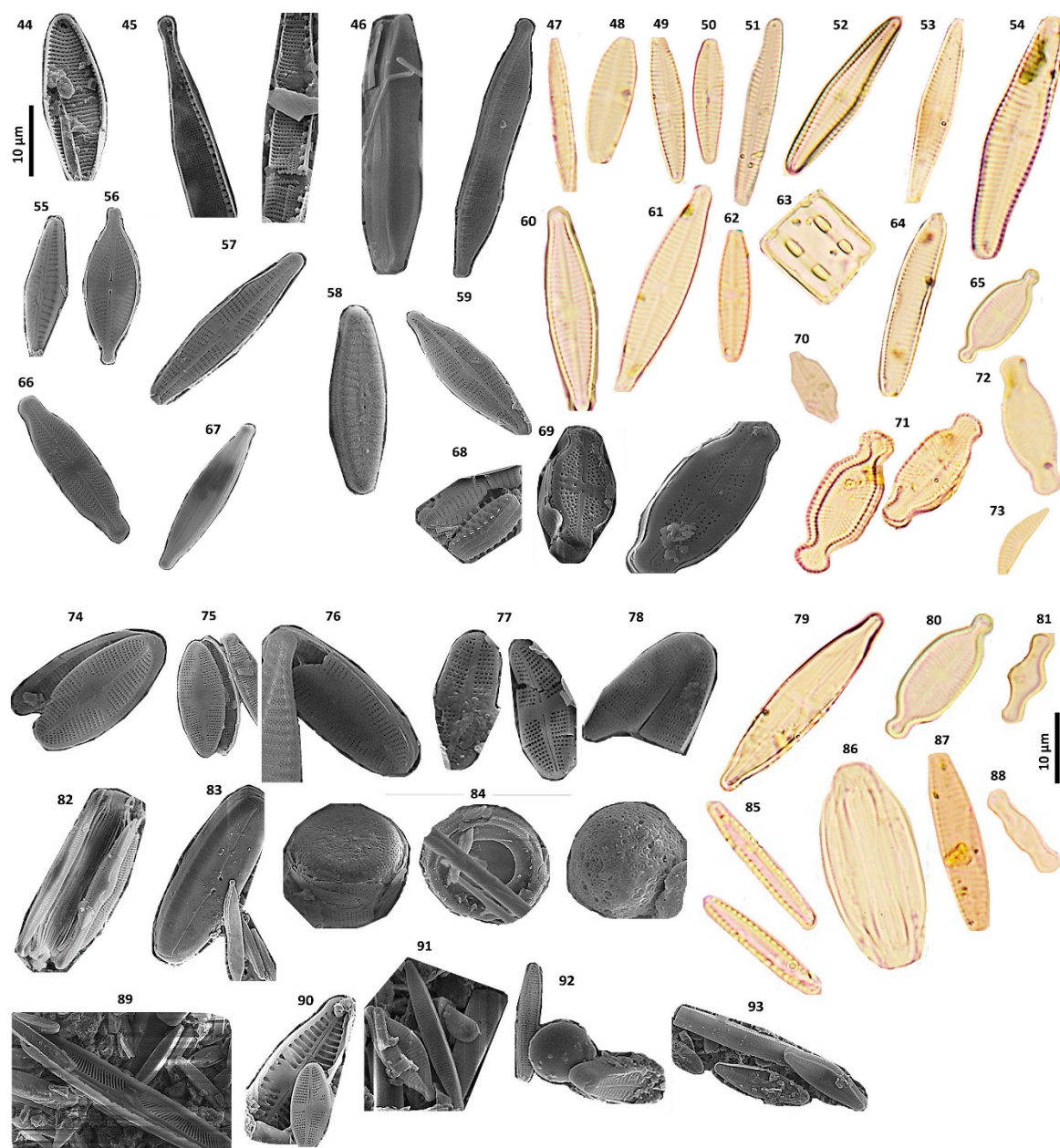


Figure 3. Continue: 44. *Achnanthes taylorensis* in OP1 45. *Nitzschia* spp. in OP1 46. *Nitzschia hamburgi* in OP1 47. *Nitzschia capitellata* in L3 48. *Gomphonema micropus* in OP2 49. *Gomphonema* cf. *sarcophagus* in OP2 50. *Gomphonema angustatum* in OP2 51. *Gomphonema* sp. in L2 52. *Gomphonema gracile* in L4 53. *Gomphonema duplipunctatum* in L4 54. *Gomphonema subclavatum* in L4 55. *Gomphonella* sp. in L2 56. *Navicula* cf. *rhynchotella* in P2 57. *Navicula libonensis* in L6 58. *Navicula* sp. in L6 59. *Navicula gregaria* in L6 60. *Navicula* cf. *slesvicensis* in L6 61. *Navicula* cf. *trilatera* in L4 62. *Navicula* cf. *veneta* in P1 63. *Diatomella balforiana* in L2 64. *Eunotia* sp. in L4 65. and 80. *Placoneis explanata* in OP1 and OP2 66. *Placoneis paraelginensis* in L6 67. *Sellaphora* sp. in L2 68. *Staurosirella* sp. in L4 69. *Luticola* cf. *muticopsis* in OP2 70. *Frustulia* sp. in P3 71. *Luticola* cf. *permuticopsis* in P3 72. *Luticola* sp. in L2 73. *Eunotia* sp. in P3 74. *Psammothidium lacustre* in P3 75. *Psammothidium helveticum* in L3 76. *Psammothidium* cf. *acidoclinatum* in L6 77. *Psammothidium* cf. *confusoneglectum* in L2 78. *Psammothidium* sp. in P2 79. *Stauroneis subgracilis* in P1 81. *Tabellaria flocculosa* in OP2 82. *Halamphora* sp. in L4 83. *Adlafia* sp. in P1 84. Unidentified centric diatoms in OP2, L1, P1 respectively 85. *Thalassionema nitzschioides* in P1 86. *Halamphora coraensis* in L4 87. *Stauroforma inermis* in P3 88. *Chamaepinnularia hassiaca* in P2 89. *Chamaepinnularia* cf. *frisca* in OP2 90. *Planothidium* sp. and *Psammothidium* cf. *confusoneglectum* in L2 91. *Planothidium delicatulum*, *Fragilaria* sp. and *Gomphonema* sp.

(From left to right) in OP2 92. Unidentified centric and pennate diatoms in L6 93. *Fragilaria* sp. and *Planothidium* sp. in P2.



Figure 3. Continue: 94. Diatom species, unidentified genus 95. Diatom species, unidentified genus, frustules in girdle view 96. *Coccolithophoride* sp. (non-diatom) in L2 97. Non-phytoplankton species, unidentified genus in L1 and L6 98. Abnormal forms of diatoms in the water and sediment samples respectively *Fragilaria capucina* in OP2 (the first three figures), *Planothidium victorii* in L4, *Craticula pseudocitrus* in L3.

The relative abundance of each diatom species in the samples was generally very rare (1-5 frustules) or rare (5-15 frustules) (Table S1). The most diatom-rich sites were L4 (31 species), OP2 (28 species), and L6 (26 species) in King George Island. Only a few diatoms were found in L1 (four species) in the Fildes Peninsula due to a lack of sediment samples for this lake. Horseshoe Island lakes also showed limited diatom species richness, with a maximum of four species in HS2. Interestingly, no diatoms could be detected in the L5 (West Lake) in Fildes Peninsula on King George Island, both in water and the sediment samples.

The correlations between diatom species richness and environmental parameters exhibited weak to strong positive relationships. HCO_3^- (Spearman $\rho = 0.78$, $p = 0.005$) and K^+ (Spearman $\rho = 0.69$, $p = 0.019$) had strong positive and significant correlations with diatom species richness, while DO (Spearman $\rho = 0.56$, $p = 0.039$) exhibited a moderate but significant positive relationship (Figure 4). Most parameters such as salinity, Na^+ , Ca^{+2} , Mg^{+2} , SO_4^{+2} , NO_3^- , and Si showed moderate positive but non-significant correlations (Figure 4). Conversely, temperature, Fe, Co, and Zi^{+2} represented weak or negligible correlations (Figure 4).

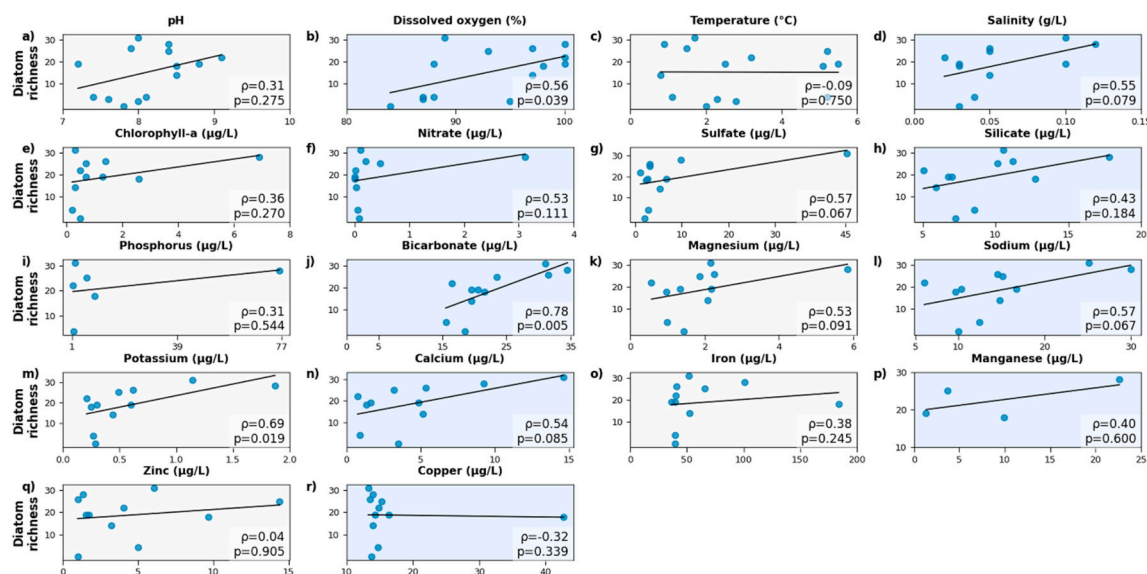


Figure 4. Correlations between diatom richness and key environmental parameters.

4. Discussion

Authors All of the studied maritime Antarctic lakes contained diatoms, except for Lake L5 on King George Island (Table S1). Most of the identified species matched to those previously reported from King George Island, including *Pinnularia subantarctica*, *Pinnularia borealis*, *Planothidium lanceolatum*, *Fragilaria capucina*, and *Nitzschia capitellata* [22,23]. Microscopic analyses revealed that the lakes on King George Island included higher numbers of diatom species than those on Horseshoe Island, which lies about 600 km farther south (Table S1). The difference between the diatom species richness across the two studied islands may be related to the considerably lower temperatures in Horseshoe Island samples, which reached a maximum of only 2.8°C (Table 2). In addition, factors such as lithology of the lake catchment area, sea spray inputs, and ornithogenic activity appear to impact water biogeochemistry, and consequently, the diatom species richness observed in the lakes on King George Island [18].

Only a few diatoms were detected in HS1, HS2, SK samples from Horseshoe Island (Table S1). The diatom genera identified in Skua Lake were *Gomphonema*, *Navicula*, and *Nitzschia* (Table S1). These results are consistent with a previous study on sediment cores from Skua Lake, except for the absence of *Pleurosigma*/*Gyrosigma* [24]. The lack of *Pleurosigma*/*Gyrosigma* in our samples may be related either to the extinction of these species or limited number of sampling sites, as only one location was considered in each lake. Horseshoe Island is characterized by abundant glacial and periglacial landforms [25] and the diatom stratigraphy in Skua Lake showed a marine-brackish-freshwater transition over the past 10,000 years [24]. Pigment concentrations, including Chl-a, in Skua Lake were previously associated with the intensity of marine influence and being located at lower latitudes, as well as potential effect of nutrient transport via faunal activity [26].

Interestingly, diatom species richness varied significantly across the lakes within a very close distance (Figure 1, Table S1). For example, only four diatom species were recorded in Lake Uruguay (L1), whereas Lake Langer (L4), Lake Yanou (L6), and the organic pond OP2 contained 31, 26, and 28 species, respectively (Table S1). Less species numbers were observed in the ponds P1, P2, P3 and OP1, with 19, 22, 25 and 18 species, respectively (Table S1). Lake Kitiesh (L2) and L3 also had similar diversity, with 19 and 14 species, respectively (Table S1).

Sediment samples showed better results compared to the analyses conducted on lake water samples, suggesting accumulation and preservation diatom frustules after deposition. In most cases, only a few diatom species were found in the water samples, whereas the sediment samples from the same lakes were richer in diatom communities. Therefore, sediment material was primarily used to

identify diatom species in the lakes. In the sediment sample from Lake Kitiesh (L2), an unidentified species with globular features, consisting of layers of circles was recognized (Figure 3, pic. 96). This organism resembled a *Coccolithophore sp.* but lacked the characteristic diagnostic features such as the central area and surrounding rim typical of *Coccolithophore sp.* [27]. Similarly, non-phytoplankton forms with an elliptical shape, a mouth-like aperture, and globular features identical to those of the unidentified species were found in samples from Lakes Uruguay (L1) and Yanou (L6) on King George Island (Figure 3, pic. 97). These findings suggest that acid treatments could influence microstructural characteristics, and therefore alternative preparation methods might be beneficial for samples collected from such remote parts of the world.

The relationship between diatom species richness and key physicochemical parameters was explored to identify potential environmental drivers of community structure (Figure 4). Among the measured variables, HCO_3^- (Spearman $\rho = 0.78$, $p = 0.005$) and K^+ (Spearman $\rho = 0.69$, $p = 0.019$) exhibited the strongest and statistically significant correlation with species richness, suggesting that carbonate chemistry and ionic balance play a significant role in shaping diatom communities. HCO_3^- bioavailability enhances the carbon supply for photosynthetic activity and supports the physiological efficiency of diatoms under low-pH or limited carbon dioxide conditions. This highlights HCO_3^- as an important environmental driver in Antarctic freshwater systems. Similarly, DO exhibited positive and statistically significant correlation with diatom species richness (Figure 4). Lakes with higher DO, such as L4, P1, P2, and OP2, included more diatom species. In contrast, lakes L1, L5, and HS2 had lower DO levels and species diversity.

Chl-a is commonly used as a proxy for primary productivity; however, its relationship with diatom species richness was moderate in our samples (Figure 4). Similarly, major ions (Na^+ , Ca^{2+} , Mg^{2+} , and SO_4^{2-}), nutrients (NO_3^- , Si, and P), Mn, salinity and pH also exhibited moderate but non-significant correlations (Figure 4), implying that these factors may contribute to diatom variability but were not dominant factors in the studied lakes. This outcome may be related to the small sample size, narrow range of variation, multiple interacting factors, or non-linear relationships. For instance, Si is essential for diatom frustules, but its concentrations were likely sufficient across all sites; therefore, it was not a limiting factor. Similarly, pH and Mn may be controlled by oxygen and HCO_3^- availabilities; hence, these interactions could obscure direct correlations.

In contrast, most trace metals (Zn^{2+} , Co, and Fe) displayed weak or negligible relationships (Figure 4), even though these parameters are biologically important for several enzymes and photosynthesis. It can be explained by the dual effect of metals as essential micronutrients and potential toxins at higher levels, as well as by their redox properties and indirect or secondary influence. Temperature also showed a weak correlation (Figure 4), suggesting a broader tolerance within the observed temperature range.

In conclusion, diatom species richness exhibited varying degrees of correlation with the measured environmental variables in the studied Antarctic lakes (Figure 4). Among these, the strongest positive relationship was observed with HCO_3^- concentrations, suggesting a potential link between alkalinity and diatom diversity in these polar freshwater systems. Additionally, lakes with higher alkalinity may provide a buffering effect that stabilizes pH fluctuations. This buffering capacity could enhance the resilience of diatom communities to environmental stress in Antarctic lakes. The influence of moderate and low correlations on diatom diversity in the studied lakes was secondary to the effect of HCO_3^- and K^+ .

5. Conclusions

This study documents 86 diatom taxa in lakes and ponds on King George and Horseshoe Islands in the Maritime Antarctic, most likely shaped by the distinct limnological characteristics of each lake. The most common species were *Planothidium lanceolatum*, *Achnanthydium dolomiticum*, *Fragilaria capucina*, and *Nitzschia homburgiensis*. Species richness showed strong positive links with HCO_3^- and K^+ , suggesting that carbonate availability and ionic composition play important roles in structuring these communities. Other variables exhibited moderate/weaker or non-significant correlations,

indicating more indirect influences. Overall, these results provide a valuable baseline and highlight a key water-chemistry parameters that could be important for future climate-related assessments in the Maritime Antarctic freshwater environments.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Table S1: Relative abundance of diatoms in sediments collected from littoral zone of lakes and ponds on King George and Horseshoe Islands, based on the light microscopy. The relative abundance of taxa in all sampling sites was shown; very rare (vr) 1-5 shells, rare (r) 5-10 shells, frequent (f) 10-30 shells, common (c) >30 shells.

Author Contributions: Conceptualization, Hilal Cura and Nazlı Olgun; methodology, Hilal Cura and Nazlı Olgun; investigation, Hilal Cura and Nazlı Olgun; laboratory work, Hilal Cura; sampling, Nazlı Olgun; writing—original draft preparation, Hilal Cura and Nazlı Olgun; resources, Nazlı Olgun, writing—review and editing, Hilal Cura and Nazlı Olgun; visualization, Hilal Cura; supervision, Nazlı Olgun; project administration, Nazlı Olgun; funding acquisition, Nazlı Olgun. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) Project #118Y372, Istanbul Technical University (ITU) Projects #42035 and #40265. The study was conducted under the auspices of the Presidency of the Republic of Türkiye, supported by the Ministry of Industry and Technology and coordinated by the Polar Research Institute of TÜBİTAK.

Acknowledgments: We thank Dr. Frederic Thalasso, Dr. Maria Soledad Astorga Espana and Dr. Lea Cabrol for their support in the field in King George in 2017. We thank Dr. Celine Lavergne for sampling on King George Island in 2019 and Dr. Atilla Yılmaz for sampling on Horseshoe Island in 2020. We thank Dr. Mehmet Baki Yokeş for his guidance and Dr. Ümmühan Sancar for her guidance in the identification of diatom species. We also thank Prof. Dr. Jose Retamales, the Chilean Antarctic Institute (INACH), Prof. Dr. Burcu Özsoy and the ITU Polar Research Center (POLREC) for the logistical support.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

Mn	Manganese
Fe	Iron
Mo	Molybdenum
Co	Cobalt
Cu	Copper
Zn ⁺²	Zinc
N	Nitrogen
Na	Sodium
Mg ⁺²	Magnesium
Si	Silica
P	Phosphorus
Ca ⁺²	Calcium
K ⁺	Potassium
HCO ₃ ⁻	Bicarbonate
NO ₃ ⁻	Nitrate
NH ₄ ⁺	Ammonium
Chl-a	Chlorophyll-a
HNLC	High-nutrient low-chlorophyll
OP1, OP2	Organic Pond
P1, P2, P3	Ponds

HS1, HS2	Horseshoe-1, Horseshoe-2
SK	Skua Lake
TAE	Turkish Antarctic Expedition
PC	Polycarbonate
DO	Dissolved oxygen
TDS	Total dissolved solids
ORP	Oxidation-reduction potentials
Temp.	Temperature
Salin.	Salinity
Con.	Conductivity
ICP-MS	Inductively coupled plasma mass spectrometer
LM	Light microscopy
SEM	Scanning electron microscope
UV-Vis	Ultraviolet-visible
DNA	Deoxyribonucleic acid
RNA	Ribonucleic acid
vr	Very rare
r	Rare
f	Frequent
c	Common
NA	Not available

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