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Diatoms (Bacillariophyta) of the world's highest aquatic environments from the Western Himalayas, India

by

Samadhan Pardhi[1,2], Thiruvalan Kokila[1], Mital Thacker[1,2], B. Alakananda[3], Balasubramanian Karthick[1,2,*]

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[1]*Biodiversity and Paleobiology Group, Agharkar Research Institute, G.G. Agarkar Road, Pune - 411004, Maharashtra, India*

[2]*Affiliated to Department of Botany, Savitribai Phule Pune University, Pune, Ganeshkind, Pune - 411007, Maharashtra, India*

[3]*Gubbi Labs, Gubbi – 572216, Karnataka, India*

* Corresponding author: karthickbala@aripune.org

Abstract

The present study is a preliminary taxonomic survey of diatom assemblages from one of the highest mountain ranges in the Western Himalayas – Ladakh. 37 samples were collected from 19 different sampling sites at altitudes ranging from 3100–4552 amsl. The diatom communities were representative of habitats such as lakes, streams, and hot springs from high altitudes. The dominant diatoms are studied using light microscopy and identified using valve morphometrics. The study enlists a total of 74 taxa belonging to 40 genera along with photomicrographic plates. Commonly-found species of high-altitude hot springs habitats were *Gogorevia exilis* and *Denticula thermaloides*. *Reimeria sinuata, Fragilaria vaucheriae, Gomphonella* cf. *olivacea, Encyonema ventricosum, Lindavia biswashanti, Diatoma moniliformis,* and *Denticula valida* were commonly occurring species in stream, river and lake habitats. Further analysis and putative novel species from this high-altitude environment will be described in future publications.

Key words: Diatoms, hot springs, Ladakh, Western Himalayas, high altitude

1. Introduction

Diatoms are distributed in different aqueous habitats ranging from freshwater to brackish waters across a varying altitudinal gradient. They are helpful environmental indicators due to the sensitivity of each species to changes in the water's physical, chemical and biological conditions (Sabater 2009). Besides colonising in freshwater and marine habitats around the world, diatoms colonise in a variety of habitats including acidic swamps, alkaline lakes, and hot springs (Hecky & Kilham 1973; Sanchez et al. 1987; Ligowski et al. 1992; Owen et al. 2008). High-altitude environments represent unique environmental settings with cold-climate and dry conditions (Wolfe 2013). Water bodies here include different categories within it, such as lakes, ponds, rivers, glaciers, glacial lakes, hot springs, etc. They are characterised by a unique diversity of water sources, habitats, species, and communities, and generally show limited human interference compared to other water bodies (Kumar and Lamsal 2016). The climatic conditions of the high-altitude region of Ladakh possess extremes of weather combinations such as extreme cold in winter, water scarcity, and intense heat in summer during the day and cold at night, along with very low atmospheric pressure and oxygen (Chaurasia et al. 2007; Dorjey 2019).

At high altitude, of more than 3500 amsl, hot springs, lakes and wetlands possesses extreme environmental conditions such as low temperatures, low nutrients, and short growing times, and they spend a large part of the year under ice and snow. Therefore, they usually have nutrient-poor conditions. This extreme climatic and physico-chemical condition supports diatom assemblage, unique to this high-altitude water bodies (Şahin and Barınova 2022).

The distinctive composition and abundance of diatom species in a water body is influenced by various factors, including pH, ionic strength, nutrient concentrations, temperature, light, oxygen saturation, and habitat availability (Patrick & Reimer 1966; Round 1981; Stevenson et al. 1996). Most of these factors depend strongly on climate, geology, topography, land use and other landscape characteristics (Potapova and Charles 2002). Thus, as each diatom species has its own specific water quality requirements, they can serve as a powerful indicator of environmental changes in the freshwater aquatic systems (Dixit et al. 1992; Smol and Stoermer 2010; Stevenson et al. 2010). However, prerequisite to the monitoring of an aquatic environment using biological organisms such as diatoms is a proper understanding of the diatom ecology, as these aquatic organisms are regularly exposed to that environment, and can provide information about the environmental conditions and the ecological health of the particular ecosystem (Thacker and Karthick 2022). Many diatom species are known to have world-wide distributions, while others appear limited to certain climatic zones or geographical regions, or are endemic to particular water bodies, such as ancient lakes. According to Kociolek & Spaulding (2000), the proportion of geographically restricted diatom species is much higher than formerly thought, which points towards the importance of geographical factors in explaining patterns in diatom flora (Potapova and Charles 2002). Thus, for diatom-based water quality monitoring, a preliminary requirement is to determine the diversity and taxonomy of diatoms, which will assist the furthering of knowledge of diatom ecology and species bio-geographical distribution.

The present work deals with the diatom diversity of one of the highest-altitude aquatic environments in the world – Ladakh, Western Himalayas. It is an arid desert with very scarce natural vegetation, and most land cover is < 3500 above mean sea level (amsl). With a highly pristine, freezing environment, precipitation and hot-spring zones scattered close to the Indus Tsangpo Suture Zone (ITSZ), Ladakh can be considered a type of area for studying life in extreme environments (Ansari et al. 2020). Researchers have studied and observed the geothermal potential and microbial biodiversity of a few hot springs across the Leh and Ladakh regions. Plants such as *Ladakiella klimesii* (Al-Shehbaz), an endemic crucifer that found at elevations up to 6150 amsl, tolerate the extreme cold of Ladakh. According to the study, 70–80% of the higher plants found in Nubra Valley of Ladakh are restricted to valley regions and not recorded in other locations (Joshi et al. 2006). Apart from plants, this region is also home to 60 percent of India's snow leopard population (Chundawat & Qureshi 1999; Guisan & Thuiller 2005).

Prior studies on the diatoms from the Western Himalayas include a pioneering work by Compère (1983) with a record of 480 algal species, out of which Kashmir and the high valleys of the Ladakh region alone comprised 229 diatoms species. Kumar et al. (2012) presented a similar study of diatoms in three high-altitude lakes and the Indus River of the trans-Himalayas, and recorded 193 species of diatoms. Recent work by Phartiyal et al. (2020) reports the late-Holocene climatic record in glacial lake sediments and documented 13 diatom taxa from Ladakh. The study revealed that *Amphora ovalis* (Kützing) Kützing showed a drastic peak, indicating the dynamics of aquatic ecosystems in the high-altitude region.

On reviewing the different studies on diatom assemblages of high altitudes worldwide, the overall altitude ranged from 1,030 amsl (Schneck et al. 2007) to 4,308 amsl (Blanco et al. 2013). In a survey of 60 high mountain lakes of Colombia's Eastern range, researchers explained how the water characteristics are significant in high-altitude ecosystems and responsible for the species composition. An investigation from the high-altitude Andean saline lakes sites (4130 to 4308 amsl) described six diatom taxa. In one of the earliest studies of diatoms in Mount Kenya, samples were collected from a high-altitude pond (4358 amsl in which the diatoms were mentioned as 'acidobionts', i.e., acidophilic species (below pH 6). However, the study did not specify the alpine character of the sites (Cholnoky 1960). A subsequent study of the Rwenzori mountains put forth the diatom diversity at high-altitude ranging from 3734–4465 amsl (Cholnoky 1964). The study by Cantonati et al. (2001) reported only a few species explicitly from unique environments such as high-altitude hot springs. Their sample locations originate from the Himalayas and reach an altitude of 4697 amsl. Colla et al. (2021) studied diatom assemblages from four saline wetlands of Argentinian Puna at an altitude of 3330 amsl. The authors explain the various environmental factors that affect ecological parameters at the diatom community level. Recently, Islam et al. (2021) studied the land use land cover (LULC) of some high-altitude mountain lakes in Kashmir Himalaya. The quality index revealed excellent water quality, while the algal composition comprised 45 diatom species amongst 61 taxa studied.

The hot springs in the Ladakh region are located in one of the world's highest mountain regions. Even though the unique biodiversity of this region is of interest due to its easily accessible terrain compared to all other high-altitude places on the Earth, the research reflecting the taxonomic and ecological account of diatoms is scarce. Hence, the present study aims to investigate and document the commonly occurring diatom flora in various aquatic ecosystems of the Ladakh region.

2. Materials and methods

2.1. Study area

The land surface of Ladakh covers an area of 95,876 km^2 encompassing two zones, a lower zone starting at the altitude of 2700–4500 amsl, and the upper zone above 4500 amsl, which covers 74 percent of the land (Smallman & Brown 2015; Bhat 2015). The present study covered the lower region and reached an altitude of 4552 amsl. The sampling sites include multiple habitats such as lakes, rivers, streams, hot springs, and Tso Moriri, a saline lake (Fig. 1). The collection of diatom samples was undertaken during May and June 2019 and September 2020. The sample details are given in Table 1.

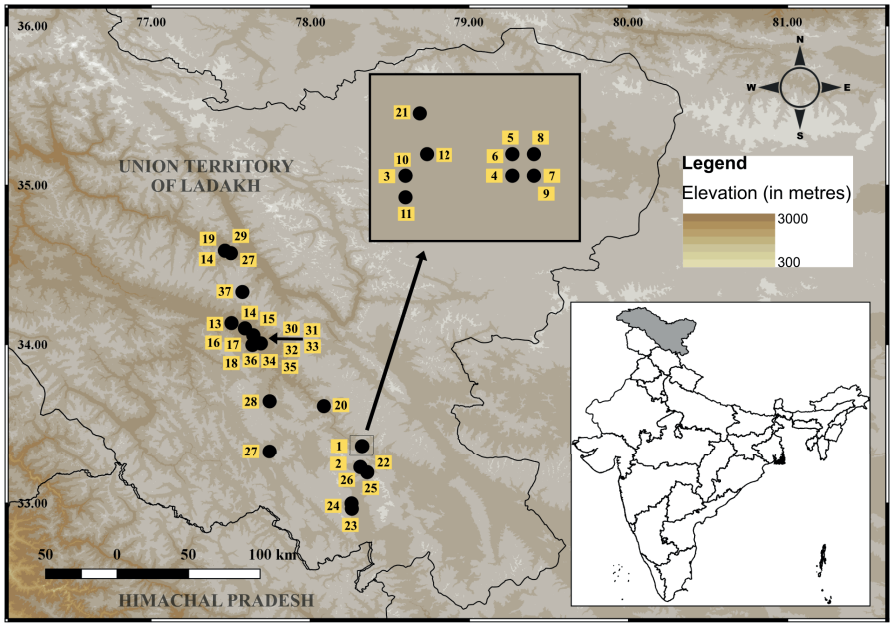

Figure 1

Map showing the different study sites of Ladakh, Western Himalayas, India

Table 1

The sample collection details of different localities of the study area (– indicates that no information is available)

S. No.	Acc. No. AHMA	Location	Habitat/Microhabitat	Latitude (°N)	Longitude (°E)	Elevation (a.m.s.l.)	Temp. (°C)	Collector's Name
1	1343	Puga, Ladakh	-	33.227699	78.303133	4422	–	Dr. Raymond Duraiswami
2	1344		-	33.227731	78.303027	4421	–	
3	1345	Chumathang hot Spring, Ladakh	Stream, Epiphytic	33.602777	78.323055	4022	80	
4	1346			33.360277	78.323055	4022	53	
5	1347			33.360555	78.324444	4028	42	
6	1348			33.360555	78.324444	4028	32	
7	1349		Pool, Epiphytic	33.360277	78.324722	4024	50	
8	1350			33.360555	78.324722	4030	50	
9	1351			33.360277	78.323055	4024	53	
10	1352		Stream, Epiphytic	33.360277	78.323055	4021	52	
11	1353			33.361001	78.323055	4017	30	
12	1354		Small man made gutter, Epilithic	33.36055	78.323333	4024	80	
13	2097	Nacho Resort, Hunder, Nubra Valley, Leh	Stream, Epibryophytic	34.58945	77.462821	3150	–	Dr. Aravind Madhyastha
14	2098		Stream, Epilithic	34.58945	77.462821	3150	–	
15	2643	Guphunks, Spituk, Leh	Pond, Epiphytic	34.1352	77.50394	3196	–	
16	2644	Indus river, Leh	River, Epilithic	34.1021	77.58858	3229	–	
17	2645		Stream, Epilithic	34.10215	77.58858	3229	–	
18	2646			34.10215	77.58858	3229	–	
19	2647	Tiri Village, Leh	Stream, Epiphytic	34.5895	77.4628	3229	–	
20	2648		River, Epiphytic	33.61345	78.08371	3705	–	
21	2649	Chumathang, Leh	River, Epilithic	33.36108	78.32324	4031	–	
22	2650	Tso Moriri Lake, Ladakh	Stream, Epilithic	33.19381	78.35872	4543	–	
23	2651		Lake, Epilithic	32.96487	78.26185	4552	–	
24	2652		Lake, Epiphytic	32.99837	78.25989	4541	–	
25	2653	Puga, Ladakh	Stream, Epiphytic	33.22669	78.31535	4420	–	
26	2654			33.22669	78.31535	4420	–	
27	2655	Tso kar lake, Leh	Lake, Epiphytic	33.32573	77.7433	4126	–	
28	2656	Gya village, (near ice stupa cafe)	Stream, Epilithic	33.64404	77.7633	4126	–	
29	2657	Hunder, Nubra valley	River, Epiphytic	34.5738	77.50023	3100	–	
30	3320	Shey-chuchot road. Indus river		34.05812	77.640838	3240	–	
31	3321			34.05812	77.640838	3240	–	
32	3322		River, Sediment+Episamic	34.05812	77.640838	3240	–	
33	3323			34.05812	77.640838	3240	–	
34	3324	Mathoo raod, near Husainiya Chuchot Gongma	River, Epilithic	33.99742	77.63501	3484	–	
35	3325	Stakna Bridge, Indus river	River, Epiphytic	34.007556	77.688138	3273	–	
36	3326		River, Epilithic	34.007556	77.688138	3273	–	
37	3327	Mughalpura, Srinagar-Leh Highway	Stream, Epiphytic	34.330304	75.572423	3271	–	

2.2. Sample collections

At each sampling site, diatoms were sampled from all possible microhabitats (epiphytic, epilithic and epibryophytic). In a clean polythene bag, the plant materials along with water were taken and shaken vigorously to dislodge the diatoms attached to the surface of the plant material. The moss-attached diatoms, also known as epibryophytic diatoms, were squeezed and washed with water to obtain a brown suspension and transferred into Whirlpak® sample bags. Epilithic diatoms were scraped with a knife or spoon and poured into sample bags that contained a small amount of water. The water temperature in the hot springs sites was measured using the HANNA handheld meter. The geographical coordinates and altitude readings were recorded at each sampling site using a GARMIN ETREX® Global Positioning System. The geo-coordinates were used to prepare the study area map (Fig. 1) using QGIS 3.14.0. Two site coordinates (S. No. 1 and 2 in Table 1) were extracted from Google Earth. The diatom samples were transported to the laboratory for further analysis.

2.3. Sample processing

The laboratory procedure involves the oxidisation of diatom samples using Nitric Acid (HNO_3) at 90°C for about 1–3 hours to remove organic matter. The process is followed by repeated rinsing and centrifugation

Table 2

List of taxa present in each of the diatom samples collected from Ladakh

S.no	Taxa name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	*Stephanocyclus meneghinianus*								+																													
2	*Lindavia biswashanti*																								+													
3	*Diatoma vulgaris*																	+	+											+			+	+				
4	*Diatoma moniliformis*						+											+	+	+														+			+		
5	*Fragilaria rinoi*													+																							+	
6	*Fragilaria vaucheriae*													+	+							+	+	+														
7	*Hannaea arcus*													+	+									+														
8	*Hannaea baicalensis*														+																							
9	*Odontidium mesodon*														+				+																			
10	*Pseudostaurosira* cf. *brevistriata*																											+										
11	*Pseudostaurosira subconstricta*																			+																		
12	*Staurosira* cf. *tabellaria*														+															+								
13	*Ulnaria ulna*																+																					
14	*Anomoeoneis sphaerophora*																+																					
15	*Stauroneis seperanda*																			+																		
16	*Brachysira* cf. *procera*																								+													
17	*Caloneis falcifera*					+	+																															
18	*Craticula simplex*	+											+														+	+					+		+			
19	*Craticula* sp.																										+						+					
20	*Fallacia pygmaea*																			+																		
21	*Frustulia vulgaris*																			+																		
22	*Navicula radiosa*																+								+					+								
23	*Navicula tripunctata*																		+													+		+		+	+	+
24	*Navicula* cf. *krammerae*																	+	+																			
25	*Navicula* cf. *libonensis*															+	+																+					
26	*Navicula cincta*	+														+											+	+										
27	*Navicula gregaria*																										+								+			
28	*Navicula caterva*																	+													+		+			+	+	
29	*Navicula reinhardtii*					+																																
30	*Pinnularia* sp.1																		+																			
31	*Pinnularia globiceps*																					+																
32	*Pinnularia brebissonii*															+						+					+	+										
33	*Neidium* sp.1					+																																
34	*Neidium bisulcatum* var. *subampliatum*					+																																
35	*Sellaphora* cf. *auldreekie*				+																															+		
36	*Sellaphora* sp.1								+																								+	+	+		+	
37	*Achnanthidium pyrenaicum*						+							+	+				+				+								+	+				+	+
38	*Achnanthidium saprophilum*						+		+	+					+									+											+			
39	*Gogorevia exilis*				+		+				+																											
40	*Cocconeis lineata*										+						+			+	+										+	+	+	+		+		
41	*Aneumastus minor*																													+								
42	*Psammothidium bioretii*																						+				+											
43	*Gomphonema minutum*																								+						+					+		
44	*Gomphonema parvulum*					+	+	+		+	+								+		+						+											
45	*Gomphonella* cf. *qii*																													+								
46	*Gomphosinica hedinii*																	+	+			+					+		+									
47	*Gomphonella* cf. *olivacea*						+	+		+								+					+	+											+			+
48	*Reimeria sinuata*													+	+				+					+			+											
49	*Amphora ovalis*																		+																			
50	*Amphora copulata*																					+																
51	*Cymbella nepalensis*				+	+													+	+									+				+					
52	*Cymbella lange-bertalotii*							+																											+				
53	*Cymbella alpestris*																											+		+		+	+		+		+	
54	*Encyonema silesiacum*																												+						+		+	
55	*Encyonema ventricosum*																		+	+			+	+								+						
56	*Encyonopsis cesatii*																													+				+	+			+
57	*Encyonopsis microcephala*																								+						+	+	+		+		+	
58	*Epithemia turgida*																+															+						
59	*Epithemia proboscidea*																+																					
60	*Epithemia sorex*																+																				+	
61	*Rhopalodia gibberula*																											+										
62	*Denticula valida*				+	+	+	+	+	+																												
63	*Denticula* thermaloides	+	+	+	+	+				+		+																										
64	*Nitzschia commutata*										+																								+			
65	*Nitzschia palea*								+							+	+		+	+																+		
66	*Nitzschia denticula*						+			+															+								+	+				
67	*Nitzschia pusilla*															+																						
68	*Nitzschia hantzschiana*											+																				+		+				
69	*Nitzschia puriformis*																						+													+		
70	*Nitzschia paleaeformis*															+	+		+													+		+	+		+	
71	*Tryblionella hungarica*				+				+												+		+												+	+			
72	*Cymatopleura apiculata*								+																														
73	*Surirella angusta*																+			+																+		
74	*Surirella brebissonii*							+																														

at 3000 rpm for 10 minutes with distilled water. The cleaning procedure is repeated at least four times or until the sample reached a neutral pH. Finally, the cleaned samples were labelled and stored in glass vials and archived at AHMA – Agharkar Research Institute Herbarium, Pune.

The cleaned material was air-dried on the coverslips and mounted with Naphrax® mounting medium for preparing permanent slides. Microscopic observations were made using the Olympus BX 53 (Tokyo, Japan) microscope, equipped with Differential Interference Contrast optics with a 100× 1.4 oil immersion objective. Light Microscopic plates were prepared using GIMP (version 2.10.22) and Inkscape (version 1.0.2) open-source software. All taxa were identified using relevant monographs and papers given under the description of each taxon. The taxa descriptions presented here are based on our measurements from the photomicrographs taken using an Olympus DP 73 digital camera with cellSens standard 1.16 imaging software.

3. Results

During the study, the highest altitude record in the Ladakh region was 4552 amsl at Tso Moriri Lake, the minimum was 3100 amsl at Hunder, in Nubra Valley. A total of thirty-seven samples from 19 different sites at varying altitudes and habitats, such as streams (16 samples), rivers (11 samples), lakes (3 samples), pools (3 samples), a pond (1 sample), unknown (3 samples) were collected. Amongst these, ten samples were from hot springs of the Chumthang region. If we classify the collection of the samples, microhabitats wise, then most of the samples were from epiphytic (20) and epilithic (12) microhabitats. The remainder of the samples were from epibryophytic (1), epipsammic (2), and unknown (2) microhabitats. We identified 74 taxa belonging to 40 genera, including 7 infraspecific (cf.) taxa and 4 unidentified taxa. The following is a list of diatom taxa provided with the literature reference, morphological data, and location with a sample accession number.

3.1. Description of characteristic features of the identified diatom taxa

Stephanocyclus meneghinianus (Kützing) Kulikovskiy, Genkal & Kociolek, 1844 Fig. 2 (1–3)

Ref. Kützing, 1844 (p. 5; pl. 30: 68); Foged, 1966 (p. 49; pl. 1; 4–8); Olszyński, R. M., & Żelazna-Wieczorek, J., 2018 (p. 164; pl. 168: 113–120; pl. 170: 127–133; Kulikovskiy, M. et al., (2022)

The valve is disc-shaped, with a typical tangential undulation of the smooth central area and a diameter of 10.0–15.6 µm and well-defined striae 9–13 per 10 µm. The valve face is flat and circular. The central area is distinct and isolated from the marginal chambered striae. The central area contains 1–3 fultoportulae, which are distinctly visible in LM.

Habitat: pool; Microhabitat: Epiphytic; Location: Chumthang Hot Springs

Lindavia biswashanti J. Mohan & Jeff R. Stone 2018, Fig. 2 (4–6)

Ref. Mohan & Stone, 2018 (p. 102; pl. 104: A–I)

The valve is similar to a disc; the valve face is separated into a hyaline central area and a marginal area with radial striae and alternating three wedge-shaped distinctly triangular depressions. The central area exhibits radial undulations and comprises 2/3 of the valve face area. The diameter is 6.8–13.6 µm and striae number 15.0–19.0 per 10 µm.

Habitat: lake; Microhabitat: Epiphytic; Location: Tso Moriri Lake, Ladakh

Diatoma vulgaris Bory 1824, Fig. 2 (7–9)

Ref. Bory, 1824 (p. 446; 1), Lange-Bertalot et al., 2017 (p. 187; pl. 4:1–6), Kulikovskiy et al., 2016 (p. 92; pl. 8:1–4), Bey & Ector, 2013 (p. 20; pl. 205:1–25)

The valve is elliptic to lanceolate with broadly-rounded sub-rostrate ends and rimoportula present near one apex of the valve. The valve length is 36.5–50 µm and the width is 10.6–11.2 µm. The central area is vacant. The axial area is linear to very narrow. The transapical ribs number 7–8 per 10 µm. Striae are not visible in LM.

Habitat: stream, river; Microhabitat: Epilithic, Epiphytic, Epipsammic; Location: Indus River, Leh, Hunder, Nubra Valley, Shey-Chuchot Road

Diatoma moniliformis (Kütz.) D. M. Williams 2012, Fig. 2 (10–12)

Ref. Williams, 2012 (p. 260; pl. 259: 3–5), Lange-Bertalot et al., 2017 (p. 185; pl. 3: 18–20), Bey & Ector, 2013 (p. 200; pl. 201: 1–43)

The valve is elliptical, lanceolate with rounded to

sub-capitate apices. The length is 19.5–32.5 µm and the width is 3.1–4.8 µm. The central area is vacant. Transapical ribs number 5–6 per 10 µm. Striae are not visible in LM.

Habitat: stream, river; Microhabitat: Epilithic; Location: Indus River, Leh, Stakna Bridge

Fragilaria rinoi Almeida & C. Delgado 2016, Fig. 2 (13, 14)

Ref. Delgado et al., 2016 (p. 248; pl. 6: 3–77)

The valve is lanceolate in larger specimens to rhombic lanceolate in smaller specimens, with rostrate ends. The length is 13.5–15 µm and the width is 5.3–5.5 µm. Pseudo-raphe narrow, linear, central area larger. The central area is vacant, although ghost striae may be present. Striae number 14 per 10 µm and are parallel to the central area, becoming slightly radiate at the poles.

Habitat: stream and river; Microhabitat: Epibryophytic, Epilithic; Location: Naycho Resort, Hunder, Nubra Valley, Leh, Indus River, Stakna Bridge.

Fragilaria vaucheriae (Kütz.) J. B. Petersen 1938, Fig. 2 (15–19)

Ref. Rumrich et al., 2000 (p. 246; pl. 247: 7–13), Roy & Keshri, 2016 (p. 9–10; pl. 10:15–16), Siver et al., 2005 (p. 91; pl. 269: 11–18)

The valve is lanceolate to linear elliptical, narrowing to rostrate, slightly capitate apices. The length is 16.2–23.5 µm, and the width is 3.2–4.3 µm. A pseudoraphe is present and narrow; the central area clearly visible on one side, and slightly inflated. Ghost striae devoid of ornamentation are observed. Striae number 10–14 per 10 µm and are mostly parallel, and radiate slightly towards the apices.

Habitat: stream; Microhabitat: Epibryophytic; Location: Naycho Resort, Hunder, Nubra Valley, Leh, and Tso Moriri Lake, Ladakh

Hannaea arcus (Ehrenb.) R. M. Patrick 1966, Fig. 2 (20–22)

Ref. Patrick & Reimer, 1966 (p. 13; pl. 4: 20), Lange-Bertalot et al., 2017 (p. 336; pl. 5: 8–12), Bixby & Jahn, 2005 (p. 222; pl. 223: 9–19)

The valve is arcuate, with a convex dorsal margin and a concave ventral margin. Apices of the valve are sub-capitate. The length is 37.4–43.7 µm and the width is 5.4–6.2 µm. The central region features a swelling of the ventral margin, and the central area is entirely vacant, although ghost striae may be present. The axial area is narrow and linear. Striae number 12–18 per 10 µm and are parallel to slightly radiate near the apices.

Habitat: stream and lake; Microhabitat: Epibryophytic and Epililthic; Location: Naycho Resort, Hunder, Nubra Valley, Leh and Tso Moriri Lake, Ladakh

Hannaea baicalensis Genkal, Popovskaya & Kulikovskiy 2008, Fig. 2 (23–25)

Ref. Genkal et al., 2008 (p. 322; pl. 1: 1–13), Vishnjakov et al., 2015 (p. 223; pl. 226: a–j), Kulikovskiy et al., 2016 (p. 99; pl. 13: 4–6)

The valve is arcuate, with tapering apices, a convex dorsal margin and concave ventral margin. It is slightly sub-rostrate at both apices. The length is 46.8–56.2 µm and the width is 6.2–6.5 µm. The central region is swollen in the ventral margin and central area is entirely vacant or has ghost striae. Axial area is narrow, linear. Striae number 17–18 per 10 µm and are parallel to slightly radiate near the apices. Striae are easily visible in LM.

Remarks: This is the first time this taxon is recorded outside the type locality (Lake Baikal). The presence of this taxon proposes that there could be some biogeography link with central Asia.

Habitat: stream; Microhabitat: Benthic; Location: Naycho Resort, Hunder, Nubra Valley, Leh

Odontidium mesodon (Kütz.) Kütz. 1849, Fig. 2 (26, 27)

Ref. Kützing, 1849 (p. 12), Lange-Bertalot et al., 2017 (p. 468; pl. 3: 6–10)

The valve is elliptical-lanceolate, with broadly rounded apices. The length is 10–12.1 µm and the width is 4.9–5.6 µm. The central area is vacant. Transapical ribs number 6–8 per 10 µm.

Habitat: stream and river; Microhabitat: Epilithic; Location: Indus River, Leh

Pseudostaurosira* cf. *brevistriata (Grunow) D.M.Williams & Round, 1988 Fig. 2 (28–32)

Ref. Williams & Round, 1988 (p. 276; 28–31); Lange-Bertalot et al., (2017 p. 530; pl. 10:27–31);

Kulikovskiy et al., 2016 (p. 101; pl. 11: 56–66)

The valve is broadly lanceolate to elliptic, with broadly rounded ends with a flat valve face. The frustules are rectangular. The length is 16.4–18.1 µm and the width is 5.6–5.9 µm. The central area is vacant. The axial area is lanceolate and wider. Striae number 9–10 per 10 µm, and are short, distinct, extend onto the mantle and are parallel to the central area and radiate toward the ends.

Habitat: lake; Microhabitat: Epiphytic; Location: Tso Moriri Lake, Ladakh

Remarks: *Pseudostaurosira brevistriata* was originally described by Williams & Round (1988, 1987, page 276, Figs. 28–31), *Fragilaria brevistriata* Grunow in Van Heurck, Syn. Diat. Belgique 157. Plate 45. Fig. 32. The valve is more linear to lanceolate and apices are narrow capitate with a striae density of 12–17 per 10 µm. (Lange-Bertalot et al., 2017, page 530, Figs. 29–31). Our specimen resembles this species but is slightly linear to lanceolate, and the apices are broad with striae density less than the described range of 9–10 per 10 µm (Tomonori Naya et al., 2007, page 65, Fig. 15, striae 14–18 vs 9–10 per 10 µm). Therefore, for the moment we are not confirming the sample as *Pseudostaurosira brevistriata*. This taxon requires further attention in future.

Pseudostaurosira subconstricta (Grunow) Kulikovskiy & Genkal 2011, Fig. 2 (33–35)

Ref. Kulikovskiy et al., 2011 (p. 366), Kulikovskiy et al., 2016 (p. 102; pl. 11: 43–46), Lange-Bertalot et al., 2017 (p. 531; pl. 10: 37–41), Куликовский et al., 2011 (p. 366; pl. 374: 74–78)

The valve is broadly lanceolate to rhombic-lanceolate, with sub-rostrate to subcapitate ends. The valve face is flat or slightly undulate due to raised costae. The length is 17.8–18.1 µm and the width is 4.0–4.1 µm. The centre margins are strongly constricted. The axial area is widely lanceolate. Striae number 18–20 per 10 µm, are distinct and parallel to radiate in the central area to slightly radiate toward the valve ends, and extend onto the valve mantle.

Habitat: stream; Microhabitat: Epiphytic; Location: Tiri Village, Leh

Staurosira* cf. *tabellaria (W. Smith.) Leuduger -Fortmorel 1878, Fig. 2 (36–38)

Ref. Morales et al., 2015 (p. 458–460; pl. 459: 48–60), Rusanov et al., 2018 (p. 6; pl. 7: 44–58)

The valve is rhomboid to lanceolate with tapering ends terminating in broadly-rounded apices. The valve shape is rhomboid to elliptical with tapering ends, ending in narrow rounded apices. The length is 8.7–13.7 µm and the width is 5–8.1 µm. The central area is vacant. The axial area is linear. Striae number 12–14 per 10 µm and are parallel at the central portion and radiate near the apices.

Habitat: stream and river; Microhabitat: Epiphytic; Location: Naycho Resort, Hunder, Nubra Valley, Leh

Remarks: Our specimen resembles the species *Staurosira tabellaria* published in Rusanov et al. 2018, having striae (13–16 per 10 µm) parallel as in *S. tabellaria*, but in our specimen, striae density (9–13 per 10 µm) is slightly different. Therefore, for the moment we are not confirming our specimen as *Staurosira tabellaria*.

Ulnaria ulna (Nitzsch) Compère 2001, Fig. 2 (39–40)

Ref. Compère, 2001 (p. 97–101), Kheiri et al., 2018 (p. 359; pl. 365: 33), Kulikovskiy et al., 2016 (p. 110; pl. 15: 4–10), John, 2018 (p. 95; pl. 350: I–J)

The valve is narrowly linear and taper from the middle towards slightly sub-capitate ends, and rimoportula are present at both ends. The length is 140–145 µm and the width is 6–6.1 µm. The central area is rectangular and contains ghost striae and shortened marginal striae. The axial area is linear, narrow and expanded slightly near to the central area. Striae 10–11 per 10 µm, parallel throughout the valve and slightly radiate at the ends.

Habitat: river; Microhabitat: Epilithic; Location: Indus River, Leh

Anomoeoneis sphaerophora Pfitzer 1871, Fig. 2 (41, 42)

Ref. Pfitzer, 1871 (p. 77; pl 3: 10); Lange-Bertalot et al., 2017 (p. 107; pl. 68: 31); Kulikovskiy et al., 2016 (p. 224; pl. 123: 1–7); Schoeman & Archibald, 1988 (p. 226; pl 225: 23–24)

The valve is linear-elliptic or rhombic-lanceolate with subrostrate to capitate ends. The length is 59–60 µm, and the width is 15.6–16.2 µm. The central area is slightly asymmetrical reaching up to the valve margin on one side. The axial area is narrow and bordered by

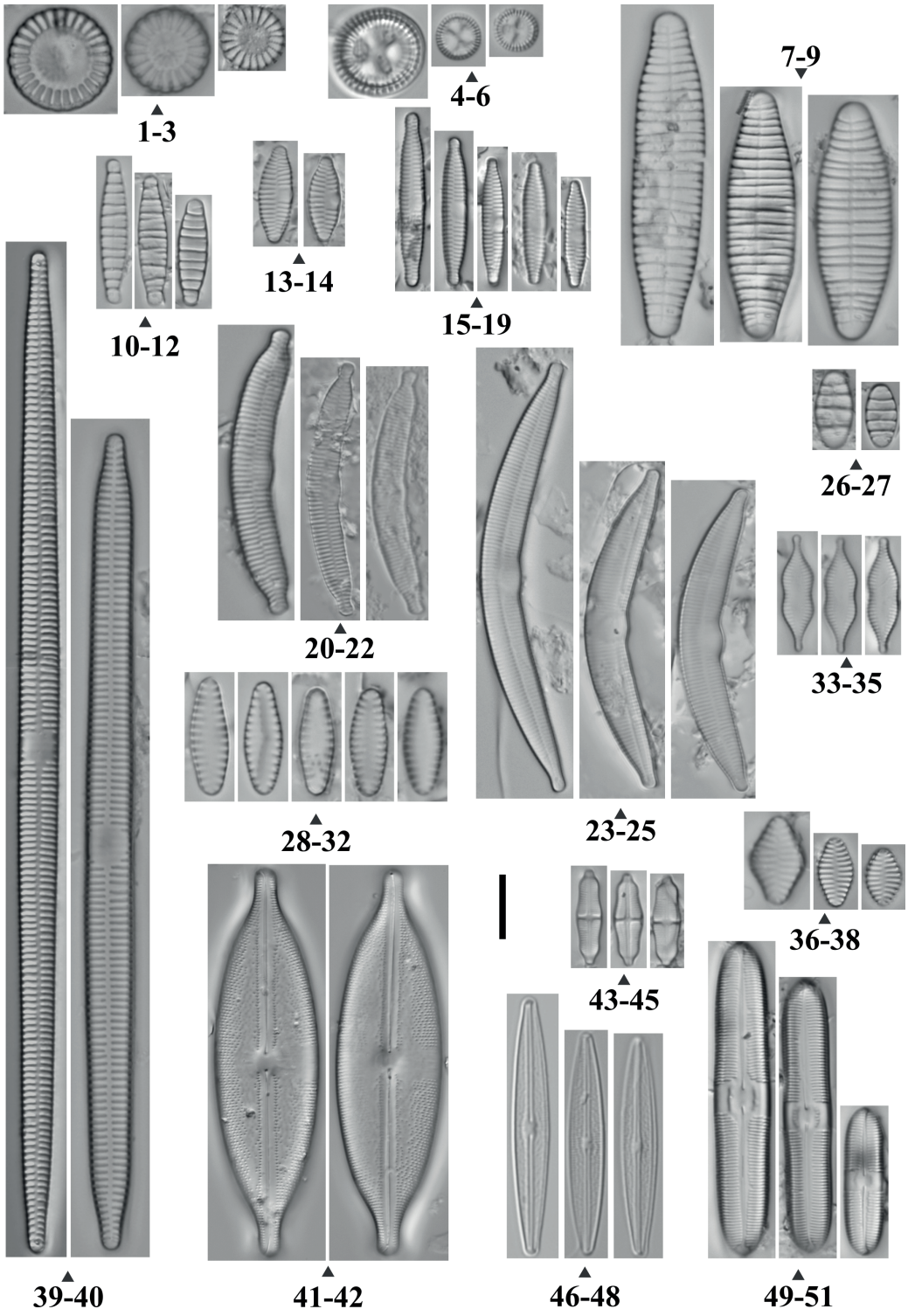

Figure 2

1-3. *Stephanocyclus meneghinianus*; 4-6. *Lindavia biswashanti*; 7-9. *Diatoma vulgaris*; 10-12. *D. moniliformis*; 13, 14. *Fragilaria rinoi*; 15-19. *F. vaucheriae*; 20-22. *Hannaea arcus*; 23-25. *H. baicalensis*; 26-27. *Odontidium mesodon*; 28-32. *Pseudostaurosira* cf. *brevistriata*; 33-35. *P. subconstricta*; 36-38. *Staurosira* cf. *tabellaria;* 39-40. *Ulnaria ulna*; 41-42. *Anomoeoneis sphaerophora*; 43-45. *Stauroneis seperanda;* 46-48. *Brachysira* cf. *procera*; 49-51. *Caloneis falcifera*. **Scale bar = 10µm**

areolae on both sides. The raphe is linear and lateral, and the terminal and distal ends of the raphe curve towards one side. The Striae number 18–20 per 10 µm and are weakly radiate at the central and parallel at the ends. Puncta pattern is distinct.

Habitat: river; Microhabitat: Epilithic; Location: Indus River, Leh

Stauroneis separanda Lange-Bert. & Werum, Fig. 2 (43–45)

Ref. Werum, M. & Lange-Bertalot, H., 2004 (p. 180; pl.46: 1–12); Levkov et al., 2016a (p. 172; pl. 169: 48–68); Lange-Bertalot et al., 2017 (p. 567; pl. 59: 4–7)

The valve is rectangular, linear to linear-lanceolate with triundulate margins and abruptly protracted apices. The central undulation is distinctly wider. In larger specimens, the valves are slightly constricted in middle. The valve length is 13.3–14.3 µm, and the width is 3.6–3.7 µm. The central area is narrow with distinct stauros. The raphe is straight and filiform. Striae are 28–30 per 10 µm. Transverse striae are fine, and are parallel throughout. Areolae are barely visible in LM.

Habitat: stream; Microhabitat: Epiphytic; Location: Tiri Village, Leh

Brachysira* cf. *procera Lange-Bert. & Gerd Moser 1994, Fig. 2 (46–48)

Ref. Lange-Bertalot & Moser, 1994 (p. 55; pl. 7, 9: 8–18, 4–6), Lange-Bertalot et al., 2017 (p. 117; pl. 60: 12, 13)

The valve is lanceolate to rhombic-lanceolate with obtusely rounded apices. The length is 33.5–39.8 µm, and the width is 5.2–5.6 µm. The central area is circular to oval. The raphe is linear and narrow. The striae number 29–30 per 10 µm and are parallel near the central area and become convergent towards the ends.

Habitat: lake; Microhabitat: Epiphytic; Location: Tso Moriri Lake, Ladakh

Remarks: *Brachysira procera* originally described by Lange-Bertalot & Gerd Moser, 1994, resembles our specimen in nearly all characteristics that can be seen with LM. However, *B. procera* has a more rhombic outline, while our specimen is more elliptical. Therefore, for the moment we are not confirming *Brachysira procera*.

Caloneis falcifera Lange-Bert., Genkal & Vekhov 2004, Fig. 2 (49–51)

Ref. Lange-Bertalot et al., 2004 (p. 12; pl. 13: Fig. 1); Lange-Bertalot et al., 2017 (p. 122; pl. 69: Figs. 29, 30)

The valve is linear with broadly rounded apices. The length is 23–48.1 µm and the width is 5.6–8.7 µm. The central area is broad, with a rectangular fascia. The axial area is linear, and is narrow at the apices. The raphe is lateral and filiform, and the proximal ends of the raphe are unilaterally deflected to one side. Striae number 22–23 per 10 µm, and are slightly radiate to parallel throughout the valve.

Habitat: stream; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh

Craticula simplex (Krasske) Levkov 2016, Fig. 3 (52–55)

Ref. Levkov et al., 2016 (p. 136; pl. 17: 1–18, pl. 18: 1–20, pl. 19: 1–6)

The valve is linear-lanceolate to rhombic-lanceolate with shortly protracted, rostrate to sub-capitate apices. The valve length is 23.0–27.5 µm and the width is 5.5–6.0 µm. The central area is vacant or weakly developed. The axial area is narrow and linear. The raphe is straight and filiform. The proximal raphe endings are expanded into central pores and are slightly deflected. The striae number 18–19 per 10 µm and are parallel to slightly radiate in mid-valve, becoming convergent towards the apices.

Habitat: stream; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh and Puga Ladakh

***Craticula* sp.** Fig. 3 (56–60)

The valve is linear-lanceolate with acute ends. The valve length is 36.0–47.5 µm and the width is 6.5–8 µm. The central area is small or weakly developed and is slightly wider than the axial area. The axial area is narrow and linear. The raphe is straight, and the proximal raphe endings are expanded. The striae number 19–20 per 10 µm, and the central striae are parallel to slightly radiate and convergent towards the ends.

Habitat: stream and river; Microhabitat: Epiphytic; Location: Puga, Ladakh and Shey-Chuchot Road, Indus River

Fallacia pygmaea (Kütz.) Stickle & D.G.Mann 1990, Fig.

3 (61, 62)

Ref. Round et al., 1990 (p. 668); Kulikovskiy et al., 2016 (p. 285; pl. 61: 35–37); Mirzahasanlou et al., 2018 (pl. 529; 32); Lange-Bertalot et al., 2017 (p. 262; pl. 47: 28–31)

The valve is elliptical with obtuse to broadly rounded apices. The length is 27.5–27.9 µm and the width is 10.2–10.6 µm. The central area is variable. The axial area is straight and narrow. The raphe is distinct, straight and filiform. The striae number 24–25 per 10 µm, and striae radiate throughout the valve. A lyre-shaped non-ornamented area is present on the valve surface. The areolae are not visible in LM.

Habitat: stream; Microhabitat: Epiphytic; Location: Tiri Village, Leh

Frustulia vulgaris (Thwaites) De Toni 1891, Fig. 3 (63–65)

Ref. Lange-Bertalot et al., 2017 (p. 284; pl. 62: 3–7)

The valve is linear-elliptical to linear-lanceolate, with apices broadly rounded or protracted. The length 50–55 µm, and the width is 9.3–9.4 µm. The central area is elongate and distinct. The raphe is well developed and lies between two siliceous ribs, and is linear and straight. The axial ribs are discontinuous and are interrupted in the central area by a central nodule. The striae number 28–30 per 10 µm, are parallel throughout the valve and are slightly or strongly convergent near the apices.

Habitat: stream; Microhabitat: Epiphytic; Location: Tiri Village, Leh

Navicula radiosa Kutz. 1844, Fig. 3 (66–68)

Ref. Kutzing, 1844 (p. 91; pl. 4: 23); Lange-Bertalot et al., 2017 (p. 401; pl. 36: 1–5); Kulikovskiy et al., 2016 (p. 335; pl. 47: 1–6); Lee, 2012 (p. 34; pl. 36: C)

The valves narrow-lanceolate, with acutely rounded apices. The length is 68.9–75.1 µm, and the width is 10.1–10.5 µm. The central area is rhombic, asymmetrical, and transversely widens to become elliptical. The axial area is very narrow. A central nodule appears to be thicker on one side. The raphe is straight and filiform, with the ends deflected onto the same side. The striae number 9–10 per 10 µm and strongly radiate, becoming convergent towards the poles. Lineolae are visible in the LM.

Habitat: river, lake; Microhabitat: Epilithic Epiphytic; Location: Indus River, Leh, Tso Moriri Lake, Ladakh and Hunder, Nubra Valley

Navicula tripunctata (O.F.Müll.) Bory 1822, Fig. 3 (69, 70)

Ref. Lange-Bertalot et al., 2017 (p. 409; pl. 36: 11–16); Kulikovskiy et al., 2016 (p. 339; pl. 49: 13–20); Lee, 2012 (p. 42; pl. 43: j, k)

The valve is linear-lanceolate, with rounded apices. The length is 48–64.3 µm, and the width is 8.1–9.3 µm. The central area is rectangular, almost reaching the margins of the valve, and has 2–3 irregular shortened striae. The axial area is narrow and distinct. The raphe is linear and straight. The striae number 10–12 per10 µm, and are slightly radiate towards the middle of the valve but are parallel towards the apices.

Habitat: stream; Microhabitat: Epilithic; Location: Indus River, Leh

Navicula* cf. *krammerae Fig. 3 (71–73)

Ref. Lange-Bertalot, H. & Metzeltin, D., 1996 (p. 79; pl. 80: 3–8,)

The valves is lanceolate with narrow, rostrate to subcapitate ends. The length is 31.2–36 µm, and the width is 6.8–7.0 µm. The central area is irregular, elliptical and widened. The axial area is narrow, linear, and widens slightly towards the central area. The raphe is lateral and filiform with comparatively narrowly spacing. The central area is strongly marked with pores. The striae number 12–14 per 10 µm and are radiate at the centre to weakly convergent at the poles. Lineolae are clearly visible in LM. The lineolae are 28–31 per 10 µm.

Habitat: river; Microhabitat: Epilithic and Epiphytic; Location: Stakna Bridge, Indus River

Navicula* cf. *libonensis, Fig. 3 (74–78)

Ref. Schoeman, 1970 (p. 342; pl. 3: 36–37), Lange-Bertalot et al., 2001 (p. 45; pl. 43: 7–14, Lange-Bertalot et al., 2017 (p. 396; pl. 30: 20–24)

The valve is narrow to broadly lanceolate with acutely rounded apices. The length is 22.5–32.0 µm, and the width is 5.4–5.6 µm. The central area is transversely elliptical or irregular-rectangular, and is often slightly asymmetrical. Axial area narrow and linear. The

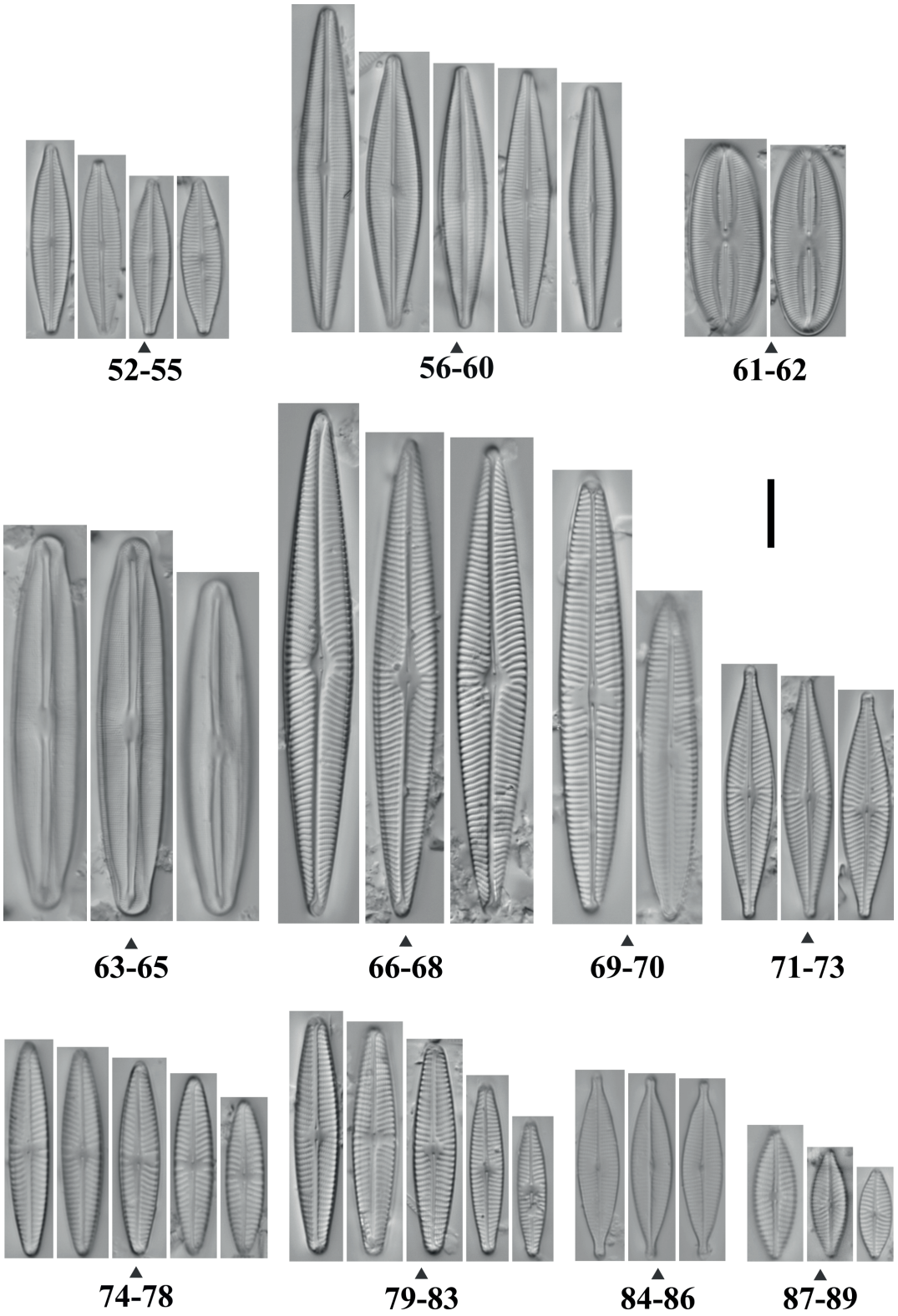

Figure 3

52-55. *Craticula simplex*; 56-60. *Craticula* sp.; 61-62. *Fallacia pygmaea*; 63-65. *Frustulia vulgaris;* 66-68. *Navicula radiosa*; 69-70. *N. tripunctata*; 71-73. *N.* cf. *krammerae*; 74-78. *N.* cf. *libonensis*; 79-83. *N. cincta*; 84-86. *N. gregaria*; 87-89. *N. caterva*. **Scale bar =10 µm**

raphe is filiform to weakly lateral, and the proximal raphe ends are straight and slightly expanded. The striae number 12–13 per 10 µm and are radiate and slightly curved at the centre of the valve, becoming convergent towards the poles.

Habitat: pond and river; Microhabitat: Epiphytic and Epilithic; Location: Guphunks, Spituk, Leh and Indus River

Navicula cincta (Ehrenb.) Ralfs 1861, Fig. 3 (79–83)

Ref. Ralfs 1861 (p. 901; pl. 40) Lange-Bertalot et al., 2017 (p. 26; pl. 41: 1–29); John, 2018 (p. 238; pl. 572: C); Lange-Bertalot et al., 2017 (p. 385; pl. 33: 31–36)

The valve is narrow to broadly lanceolate with acutely narrow apices. The length is 19.5–32 µm, and the width is 4.3–6.2 µm. The central area is small with an irregular border. The axial area is narrow and linear. The raphe is filiform to weakly lateral. The proximal ends are slightly expanded and both distal raphe ends curve towards the second valve. The striae number 12–16 per 10 µm, are strongly radiate and are convergent at the ends.

Habitat: pond and stream; Microhabitat: Epiphytic; Location: Guphunks, Spituk, Leh and Pond

Navicula gregaria Donkin 1861, Fig. 3 (84–86)

Ref. Donkin, 1861 (p. 10; pl. 1: 10); Lange-Bertalot et al., 2017 (p. 396; pl. 40: 4–6); Foged, 1978 (p. 90; pl. 206: 9); Lange-Bertalot et al., 2001 (p. 11; pl. 94: 19–24)

The valve is lanceolate with weakly protracted acutely rounded apices. The length is 26.2–27 µm, and the width is 5.8–6.1 µm. The central area is variable, asymmetrical and bordered by short striae. The axial area is narrow and straight. The raphe is filiform to weakly lateral. The proximal ending is strongly deflected. Striae number 18–20 per 10 µm and are slightly radiate at the centre and parallel to convergent at the apices.

Habitat: stream and river; Microhabitat: Epilithic; Location: Gya Village and Puga, Ladakh

Navicula caterva Hohn & Hellerman 1963, Fig. 3 (87–89)

Ref. Lange-Bertalot et al., 2001 (p. 25; pl. 33: 1–10, pl. 70:1)

The valve is broadly lanceolate with shortly protracted, subrostrate ends. The length is 14.9–17.4 µm and the width is 4.8–6.2 µm. The central area is small and irregular. The axial area is linear and very narrow. The raphe is filiform and straight. Striae number 17–18 per 10 µm and are radiate and curved near the centre and convergent at the valve apices.

Habitat: stream, river; Microhabitat: Epilithic, Epiphytic; Location: Indus River, Leh, Shey-Chuchot Road

Navicula reinhardtii (Grunow) Grunow 1880, Fig. 4 (90–92)

Ref. Van Heurck, 1880 (pl. 7: 7), Lange-Bertalot et al., 2017 (p. 403; pl. 28: 9–11), Lee 2012 (p. 35, 36; pl. 36: E); Lange-Bertalot et al., 2001 (p. 63; pl. 3: 1–5)

The valve is broadly elliptical to lanceolate with broadly rounded ends. The length is 33.2–54.3 µm, the width is 14.5–15.0 µm. The axial area is narrow and the central area is transverse, formed by alternating short and long striae. The raphe is filiform; the raphe branches are nearly straight, and the proximal raphe ends are straight, small and bulbous. Striae number 8–9 per 10 µm and are wide and radiate and nearly parallel at the ends. Lineolae are easily visible in LM.

Habitat: Stream; Microhabitat: Epiphytic; Location: Chumathan Hot Springs, Ladakh

***Pinnularia* sp. 1** Fig. 4 (93, 94)

The valve is linear, margins triundulate with slightly sub-capitate apices. The length is 32.2–36.2 µm and the width is 5.6–5.8 µm. The central area is broad with transverse fascia. The axial area is narrow, widening towards the centre. The raphe is straight, and the terminal nodules are distinct. Striae number 18–20 per 10 µm and are radiate in the central area and convergent towards the apices.

Habitat: stream; Microhabitat: Epilithic; Location: Indus River, Leh

Remarks: This taxon morphologically resembles *Pinnularia nodosoides* Krasske (cf. Krasske, 1948, pl. 2: 10) but has a wider fascia and a coarser stria, radiate to convergent throughout the valve. This taxon needs a taxonomic enumeration in future.

Pinnularia globiceps W. Gregory 1856, Fig. 4 (95–97)

Ref. Krammer, 2000 (p. 97; pl. 75: 10–12); Kulikovskiy et al., 2016 (p. 298; pl. 78: 6)

The valve is linear, lanceolate with constricted and slightly capitate rounded ends. The length is 24.5–48.7 µm and the width is 7.5–11.0 µm. The central area is large, transverse and elongate. The axial area is narrow, with a width of approx.1/4 of the width of the valve, expanding broadly into the central area. The raphe is filiform with drop-shaped curved proximal ends. Striae number 10–14 per 10 µm and strongly radiate in the middle portion and converge at the ends.

Habitat: river; Microhabitat: Epilithic; Location: Chumthang, Leh

Pinnularia brebissonii (Kutz.) Rabenh. 1864, Fig. 4 (98–101)

Ref. Rabenhorst, 1864 (p. 222); Krammer et al., 2000 (p. 69; pl. 45: 1–17); Lange-Bertalot et al., 2017 (p. 481; pl. 72: 9–3); Hofmann et al., 2013 (p. 482; pl. 70: 9–13)

The valve is linear to elliptic, with parallel margins in larger specimens. The ends are broadly apiculate. The length is 25.6–31.2 µm and the width is 6.6–7 µm. The central area is broad with a rhombic fascia. The axial area narrows at the ends and is wider towards the central area. The raphe is weakly lateral and straight. The proximal raphe ends are distinctly inflated and laterally deflected. Terminal raphe fissures are deflected to the primary valve side and are shaped like question marks. Striae number 16–20 per 10 µm and are strongly radiate near the central area, are parallel in the middle and convergent near the apices. Lineolae are easily visible in LM.

Habitat: river, pond and stream; Microhabitat: Epilithic, Epiphytic; Location: Guphunks, Spituk Leh, Puga, Ladakh

***Neidium* sp. 1** Fig. 4 (102, 103)

The valve is broadly linear and rounded at the ends. The length is 32–38 µm and the width is 9.0–9.7 µm. The central area is small and transversely elliptical, and the proximal ends of the raphe curve in opposite directions. The axial area is filiform and narrow. Striae number 14–15 per 10 µm and are distinctly punctate, throughout the valve they are slightly radiate to parallel and are slightly convergent at the apices.

Habitat: stream; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh

Remarks: This taxon morphologically resembles *Neidium distincte-punctatum* Hustedt (cf. Liu et al., 2017, p. 24: 247–252), but the central area is transversely elliptical reaching up to the margin and the ends are slightly narrow, and the striae density differs from the aforementioned species.

Neidium bisulcatum* var. *subampliatum Krammer 1985**,** Fig. 4 (104, 105)

Ref. Lange-Bertalot et al., 2017 (p. 423; pl. 54:14)

The valve is broadly linear with broadly rounded ends. The length is 45.8–53 µm, and the width is 9.4–9.6 µm. The central area is transversely circular, and the ends of the raphe curve in opposite directions. The axial area is distinct. Striae number 18–20 per10 µm and are distinctly punctate, and are parallel to slightly radiate throughout the valve. Punctae are easily visible in LM, 20 in 10 µm.

Habitat: stream; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh

Sellaphora* cf. *auldreekie D. G. Mann & S. M. McDonald 2004, Fig. 4 (106–108)

Ref. Mann et al., 2004 (p. 477; pl. 4 m–o: 43–47)

The valve is linear, lanceolate, or elliptical with bluntly rounded apices. The length is 23.5–25.6 µm and the width is 6.8–7.5 µm. The central area has butterfly-shaped fascia that extend halfway to the valve. The axial area is narrow, linear and broadened at the centre. The raphe is filiform, straight or weakly undulate, with a dot-shaped central pore. Striae number 22–26 per 10 µm and are radiate, parallel towards the poles, and bilaterally delimited from the hyaline axial area by a more strongly defined line. Shortened striae flanking the central area can be alternately short or long.

Habitat: stream; Microhabitat: Epiphytic; Location: Chumthang Hot Springs, Ladakh and Mughalpura, Srinagar-Leh Highway

***Sellaphora* sp. 1** Fig. 4 (109–111)

The valve is broadly linear with parallel margins and rounded apices. The length is 28.2–31.2 µm and the width is 8.6–8.8 µm. The central area is orbicular. The axial area is narrow and is bordered on each side by a conopeum. The raphe is straight with slightly expanded proximal end. Striae number 14–16 per 10 µm and are curved radiate throughout the valve.

Habitat: pool and river; Microhabitat: Epiphytic and Epilithic; Location: Chumathang Hot Springs, Ladakh and Shey-Chuchot Road, Indus River.

Remarks: This taxon morphologically resembles *Sellaphora laevissima* (Kützing) D. G. Mann (cf. Mann et al., 2008 p. 15–78; 51) but differs in having a central area more rhombic in shape, with slightly radiate and curved striae.

Achnanthidium pyrenaicum (Hust.) H.Kobayasi 1997, Fig. 4 (112–116)

Ref. Kobayasi, 1997 (p. 148), Lange-Bertalot et al., 2017 (p. 89; pl. 23: 62–70); Monnier et al., 2007 (p. 145; pl. 148: 33–36); Potapova & Ponader, 2004 (p. 44; pl. 45: 72–80)

The valve is linear-elliptic, with rounded or slightly protracted apices. The raphe valve is concave; the axial area is linear-lanceolate. The length is 12.5–20.6 µm and the width is 4.1–4.2 µm. The Raphe is filiform and straight with proximal ends teardrop-shaped externally, and curved internally. Distal ends curved in same sides externally, and curved in opposite sides internally. The rapheless valve is convex with a narrow, linear axial area widening slightly in the central area of the valve. Striae number 20–22 per 10 µm and are parallel in both valves and slightly radiate near the apices.

Habitat: stream and river; Microhabitat: Epiphytic, Epibryophytic and Epilithic; Location: Chumathang Hot Springs, Ladakh; Naycho Resort, Hunder, Nubra Valley, Leh and Indus River, Leh

Achnanthidium saprophilum (H.Kobayasi & Mayama) Round & Bukhtiyarova 1996, Fig. 4 (117–120)

Ref. Round & Bukhtiyarova, 1996 (p. 349); Lange-Bertalot et al., 2017 (p. 90; pl. 24: 53–57); Kulikovskiy et al., 2016 (p. 228; pl. 35: 17–18); Hlúbiková, 2011 (p. 33; pl. 24: 118–147)

The valve is linear-elliptical, the ends are weakly drawn out and are broadly rounded. The length is 10.6–13.7 µm, and the width is 2.8–3.1 µm. The central area in the raphe valve is transversely broadened with fascia that do not reach the margin, whereas in the raphe-less valve it is absent or indistinct. The axial area is narrowly to more broadly lanceolate. Striae number 28–30 per 10 µm, and are weakly radiate towards the ends.

Habitat: stream, pool, lake and river; Microhabitat: Epiphytic, Epilithic; Location: Chumathang Hot Springs, Ladakh; Naycho Resort, Hunder; Nubra Valley, Leh; Tso Moriri Lake, Mathoo Road, Husainiya Chuchot Gongma

Gogorevia exilis (Kützing) Kulikovskiy & Kociolek 2020, Fig.4 (121–123)

Ref. Lange-Bertalot et al., 2017 (p. 84; pl. 23: 31–36); Taylor et al., 2014 (p. 45; pl. 45: 2–54); Kulikovskiy M. et al., 2020

The valve is elliptical to linear-elliptical with protracted rostrate apices. Both the raphe and the rapheless valve have a narrow and slightly sigmoid axial area; the raphe valve has fascia and the rapheless valve has a small, transapically rectangular, often asymmetric central area. The length is 17.4–19.5 µm, and the width is 6.7–7.4 µm. The raphe is straight but deflected to opposite sides near the apices. Striae number 18–20 per 10 µm and are slightly radiate on both valves, but are almost parallel at the apices.

Habitat: stream; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh

Remarks: This diatom species was exclusively found only in the Hot springs samples collected from Chumthang Hot Springs.

Cocconeis lineata Ehrenb. 1849, Fig. 4 (124–128)

Ref. Ehrenberg, 1849 (p. 301; pl. 5: 44); Lange-Bertalot et al., 2017 (p. 138; pl. 20: 8, 9); Kulikovskiy et al., 2016 (p. 246; pl. 31:1–9)

The valve is elliptic to linear-elliptic. The raphe valve has a narrow axial area and an elliptical to circular central area. The length is 21.2–25 µm and the width is 14.1–16.8 µm. The raphe is straight and filiform. The distal raphe ends are straight and expanded externally. The proximal raphe ends are straight externally and slightly expanded. Striae number 20–21 per 10 µm, are parallel and straight in the centre and radiate towards the apices. The areolae are visible under LM.

Habitat: stream, river; Microhabitat: Epiphytic, Epilithic; Location: Chumathang Hot Springs, Ladakh; Indus River, Leh; Shey-Chuchot Road, Indus River; Stakna Bridge, Indus River

Aneumastus minor Lange-Bert. 1993, Fig. 4 (129–131)

Ref. Lange-Bertalot et al., 1993 (p. 1–164, pl. 39; 8, pl. 40; 1–4); Lange-Bertalot et al., 2017 (p. 104; pl. 103: 6–10)

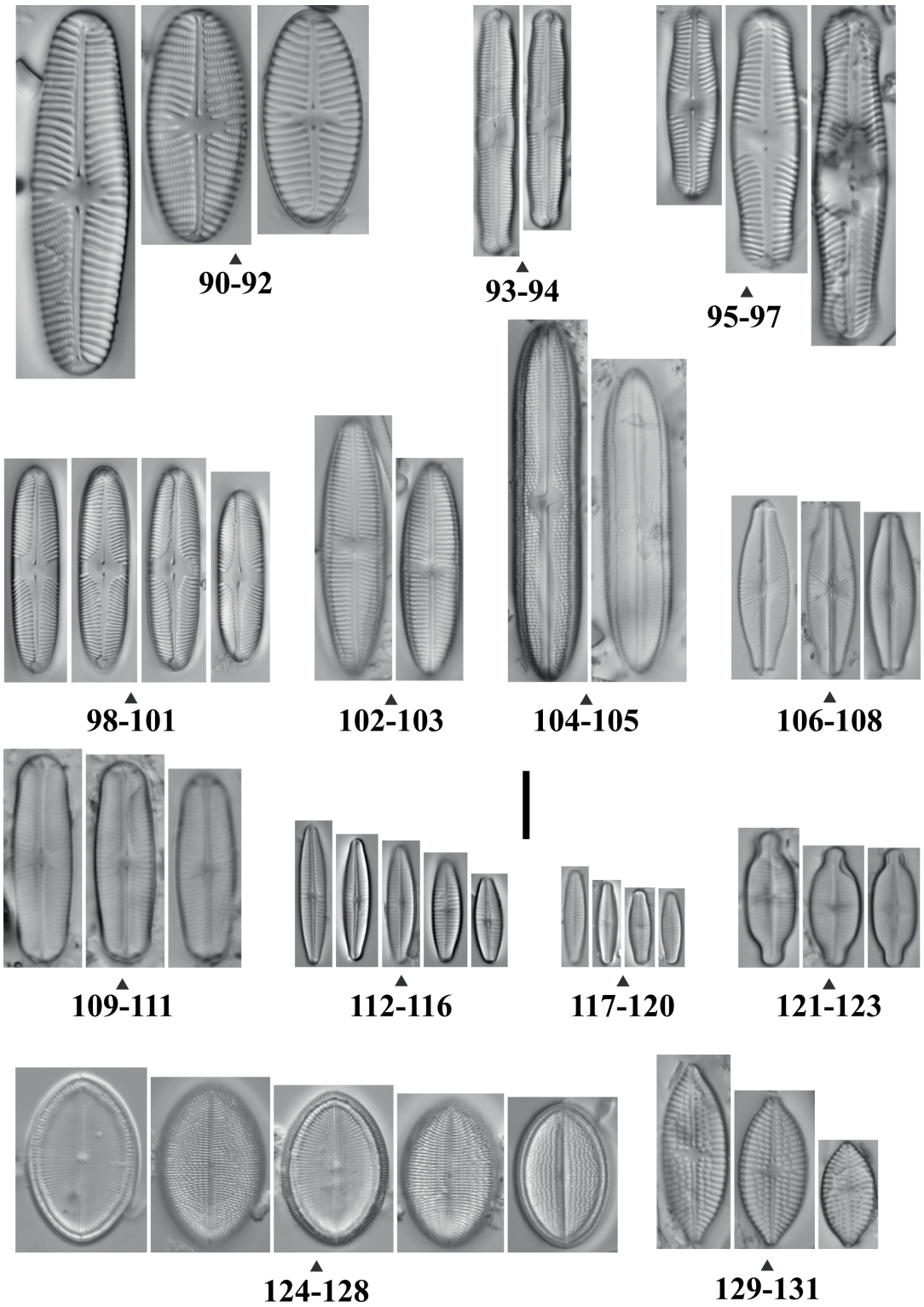

Figure 4

90-92. *Navicula reinhardtii*; 93-94. *Pinnularia* sp.1; 95-97. *Pinnularia globiceps*; 98-101. *P. brebissonii*; 102-103. *Neidium* sp.1; 104-105. *Neidium bisulcatum* var. *subampliatum*; 106-108. *Sellaphora* cf. *auldreekie;* 109-111. *Sellaphora* sp.1; 112-116. *Achnanthidium pyrenaicum*; 117-120. *A. saprophilum*; 121-123. *Gogorevia exilis*; 124-128. *Cocconeis lineata*; 129-131. *Aneumastus minor*. **Scale bar = 10µm**

The valve is broadly lanceolate with rounded apices. The valve length is 15.6–26.2 µm, width 8.1–10.0 µm. The axial area is narrow and linear. The central area is small and irregular with 2–3 shortened striae on each side. The raphe is straight, with slightly enlarged proximal raphe ends. The striae are radiate, numbering 11–14 per 10 µm. The areolae in the central region are transversely elongate.

Habitat: river; Microhabitat: Epiphytic; Location: Hunder, Nubra Valley.

Psammothidium bioretii (H.Germ.) Bukhtiyarova & Round 1996, Fig. 5 (132–135)

Ref. Bukhtiyarova & Round 1996 (p. 9; 26–31); Lange-Bertalot et al., 2017 (p. 520; pl. 27: 14–18); Kulikovskiy et al. 2016 (p. 239; pl. 35: 35–39), Manoylov et al., 2007 (p. 318–320; pl. 319: 1–10)

The valve is broadly elliptical and both ends broadly rounded. The length is 10.2–20.6 µm and the width is 5.4–9.3 µm. The central area is transversely elliptical or rectangular with shortened striae. The axial area is narrow. The raphe is filiform and straight. The rapheless valve central area and axial area is narrow and rarely wider. Striae number 20–28 per 10 µm and are radiate throughout the valve.

Habitat: stream; Microhabitat: Epilithic and Epiphytic; Location: Tso Moriri Lake, Ladakh and Puga

Gomphonema minutum (C.Agardh) C.Agardh 1831, Fig. 5 (136–139)

Ref. Agardh, 1831 (p. 34); Lange-Bertalot et al., 2017 (p. 311; pl. 824: 28–32); Kociolek, J. P. & Kingston, J. C., 1999 (p. 698; 699: 78–90)

The valve is broadly wedge-shaped or club-shaped to lanceolate with a strongly narrowed foot pole and broadly rounded head pole. The length is 16.5–25.6 µm and the width is 4.8–5 µm. The central area is very small, and the axial area is narrow. The stigma present in the centre is large and distinct. The raphe weakly curved in larger specimens. Striae number 12–15 per 10 µm and are radiate throughout the valve.

Habitat: lake; Microhabitat: Epiphytic; Location: Tso Moriri Lake, Ladakh.

Gomphonema parvulum (Kutz.) Kutz. 1849, Fig. 5 (140–144)

Ref. Kutzing, 1849 **(**p. 65); Lange-Bertalot et al., 2017 (p. 315; pl. 830: 1–5); Kulikovskiy et al., 2016 (p. 213; pl. 128: 12–17); Levkov et al., 2016b (p. 98; pl. 348: 1–19)

The valve is lanceolate; the ends are rostrate to sub-capitate and slightly deflected. The length is 18–26.2 µm and the width is 5.6–6.4 µm. The central area is asymmetrical, with a single long stria on one side. One distinct stigma is present. The axial area is narrow and straight. The raphe is straight and slightly undulate with slightly expanded proximal ends, with a polar node visible at each pole before the apices, and an indistinct terminal impression. Striae number 12–16 per 10 µm. Striae are more or less parallel throughout the valve and are slightly radiate towards the foot pole; striae are more widely spaced at the centre of the valve. Areolae are not visible in LM.

Habitat: stream; Microhabitat: Epiphytic, Epilithic; Location: Chumathang Hot Springs, Ladakh; Indus River, Leh; Tiri Village, Puga, Shey-Chuchot Road.

Remarks: This diatom species was found mostly in hot springs samples collected near Chumathang.

Gomphonella* cf. *qii (Q. M. You & Kociolek) R. Jahn & N. Abarca 2019, Fig. 5 (145, 146)

Ref. You et al., 2013 (p. 6: 26–38)

The valve is weakly linear to elliptical-clavate and the ends are obtusely rounded. The length is 40.1–60.8 µm and the width is 7.5–11 µm. The central area is transversely rectangular and almost reaches the valve margins and has very short stria on each side. The axial area is narrow. The raphe branches are curved, but appear to be filiform. Striae number 7–10 per 10 µm and are radiate in the centre to parallel in the apices.

Habitat: river; Microhabitat: Epiphytic; Location: Hunder, Nubra Valley.

Remarks: *Gomphonella qii* originally described by You et al., 2013, p. 6: 26–38 from the Kunlun Mountains in the west of Xinjiang Province, China, have a sub-capitate head pole (You et al., 2013, p. 6: 26–30). In our specimen, the valve differs slightly, with a capitate head pole. Jüttner et al., 2018 (p. 289; 39–45) reported this species from Rara Lake, Nepal. Striae range from 12–14 per 10 µm, but a lower striae density of 7–10 per 10 µm was observed in our specimen. Therefore, for the moment we are not confirming our specimen as *Gomphonella qii*.

Gomphosinica hedinii (Hust.) Kociolek, Q.M.You, Q.X.Wang & Q.Liu 2015, Fig. 5 (147–151)

Ref. Kociolek et al., 2015 (p. 184 pl. 184: 47–54); Kulikovskiy et al., 2016 (p. 216; pl. 124: 62–65)

The valve is lanceolate-clavate with both ends capitate. The head pole is broader and more rostrate while the foot pole is narrow. The length is 30.7–36.8 µm and the width is 8.8–9.9 µm. The central area bears a single round stigma. The axial area is straight and narrow and expanded laterally with a stria of varying length on both sides, giving the impression of an X-shaped central area. The raphe is lateral and straight. Striae number 10–12 per 10 µm and are strongly radiate at the centre, parallel at both ends, and not clearly punctate. The apical pore fields are indistinct.

Habitat: stream, river; Microhabitat: Epilithic, Epiphytic; Location: Indus River, Leh; Chumathang, Puga, Ladakh

Gomphonella* cf. *olivacea (Hornem.) Rabenh. 1853, Fig. 5 (152–154)

Ref. Rabenhorst, L. (1853) (1853: 61, pl. IX [9]: Fig. 1); Jahn, 2019 (p. 231 pl. 266: A–H, M-P); Tuji, 2005 (p. 97; pl. 15: 1–15)

The valve is clavate with broadly rounded headpole and narrow towards the foot pole. The length is 18.1–25.1 µm and the width is 6.0–7.5 µm. The axial area is moderately narrow to broadly linear. The central area is variable, transversely broad but not reaching up to the margins. Stigma is absent. The raphe is filiform and slightly wider, almost straight. Striae number 10–12 per 10 µm and are radiate, becoming parallel and even very weakly convergent close to the head pole.

Remarks: *Gomphonella olivacea* was originally described by Rabenhorst, L. (1853) (1853: 61, pl. IX [9]: Fig. 1). Our specimen resembles this species with a slight difference in the central area (the central area expands to form a rectangular, bow-tie- to transversely elliptical shape). Therefore, for the moment we are not confirming our specimen as *Gomphonella olivacea*. The taxonomic study confirmation will be detailed in future.

Habitat: stream, pool; Microhabitat: Epiphytic, Epilithic; Location: Chumthang Hot Springs; Indus River, Leh; Tso Moriri Lake, Ladakh; Mathoo Road near Husainiya Chuchot Gongma, and Mughalpura, Srinagar-Leh Highway

Reimeria sinuata (W.Greg.) Kociolek and Stoermer 1987, Fig. 5 (155–157)

Ref. Kociolek and Stoermer, 1987 (p. 457; 1–10), Levkov & Ector, 2010 (p. 482; pl. 474: 34–40); John, 2018 (p. 168; pl 478: G–H); Lange-Bertalot et al., 2017 (p. 533; pl. 91: 50–56)

The valve is dorsiventral and narrowly lanceolate with convex ventral and dorsal margins. The ventral margin is slightly inflated mid-valve. The ends are broadly rounded to sub-capitate. The valve length is 10.3–22 µm and the width is 3–5 µm. The axial area is very narrow and linear. The central area is wider on the ventral side, extending up to the ventral margin, whereas on the dorsal side one short central stria and an isolated stigma is present. the raphe branches linearly and are filiform to slightly lateral. The proximal raphe endings are indistinct and slightly ventrally bent, while the distal raphe endings are ventrally curved. Striae number 10–14 per 10 µm and are subparallel or slightly radiate throughout the valve. Areolae not discernible with LM.

Habitat: stream, lake; Microhabitat: Epibryophytic, Epilithic, Epiphytic; Location: Naycho Resort, Hunder, Nubra Valley, Leh; Indus River, Leh; Tso Moriri Lake, Ladakh; Puga

Amphora ovalis (Kütz.) Kütz. 1844, Fig. 5 (158, 159)

Ref. Kützing, 1844 (p. 107; pl. 5: 35, 39); Levkov, 2009 (p. 96; pl. 322:1–6); Lange-Bertalot et al., 2017 (p. 101; pl. 92: 1–5); Kulikovskiy et al., 2016 (p. 286; pl. 38: 1–10)

The valve is semi-elliptical with a smoothly arched dorsal margin and a straight or slightly concave ventral margin. The valve ends are obtusely rounded. The valve length is 40.0–59.0 µm and the width is 8.7–12.0 µm. The central area is interrupted by intercostal ribs on the dorsal side. Therefore, dorsal fascia are absent, but ventral fascia are present and extend to the valve margin. The axial area is narrow and curved. The raphe branches are double-curved at both ends displaced dorsally. Striae number 10–12 per 10 µm, are radiate throughout, and coarsely punctate. The central striae are dash-shaped and not punctate.

Habitat: stream; Microhabitat: Epilithic; Location: Indus River, Leh

Amphora copulata (Kütz.) Schoeman & R. E. M. Archibald 1986, Fig. 5 (160, 161)

Ref. Schoeman & Archibald, 1986 (p. 429; 11–13, 30–34), Lange-Bertalot et al., 2017 (p. 98; pl. 93: 4–8); John, 2018 (p. 258; pl. 601: H–F), Levkov, 2009 (p. 49: pl. 47: 10–16)

The valve is semi-lanceolate to semi-elliptical with smoothly arched dorsal margin and a concave ventral margin. The length is 27.5–31.2 µm and the width is 6.8–7.5 µm. The axial area is narrow. The proximal raphe ends are dorsally inclined and the distal raphe ends are curved towards the dorsal side. Dorsal and ventral fascia are present. Striae number 12–14 per 10 µm, and the dorsal striae are almost parallel in the middle and radiate slightly towards the apices. The ventral striae radiate in the middle and are convergent towards the ends.

Habitat: pool, stream, river; Microhabitat: Epiphytic, Epilithic; Location: Chumathang Hot Springs Ladakh; Indus River, Leh; Shey-Chuchot Road.

Cymbella nepalensis (Jüttner & Van de Vijver) Vishnjakov 2015, Fig. 5 (162–164)

Ref. Vishnjakov et al., 2015 (p. 326; pl. 329: f–j); Kulikovskiy et al., 2016 (p. 171; pl. 89: 5–11)

The valve is broad, cymbelloid and semi-elliptical. The apices are bluntly rounded and weakly protracted. The dorsal margin is strongly arched, and the ventral margin is slightly convex to nearly flat. The valve length is 45.1–63.8 µm and the width is 14–19 µm. The central area is oval or slightly rhombic. 2–5 ventral stigma and usually 4 stigmata are seen. The axial area is linear and wider than the raphe. The ends of the large valves are not protected but are truncated and widely rounded. Small valves have more or less clearly protracted ends. Striae number 8–10 per 10 µm, and the ventral striae are weakly radial. Areolae are distinct in LM.

Remarks: Previously, this species was known from Nepal and from the rivers Selenga, Olkha, Onot, Zun-Muren & Malie Tibeliti and Lake Baikal. This study marks that first time it has been reported in India.

Habitat: stream; Microhabitat: Epiphytic, Epilithic; Location: Chumthang Hot Springs, Ladakh; Indus River, Leh, Gya Village

Cymbella lange-bertalotii Krammer 2002, Fig. 5 (165, 166)

Ref. Krammer, 2002 (p. 152, 174; pl. 179: 1–6, pl. 180; 1–8. pl. 181: 1–6, 8; pl. 182: 1–9), Kulikovskiy et al. 2016 (p. 170; pl. 99: 8–11), Barinova et al. 2014 (p. 25; pl. 26: 8).

The valve is slightly dorsiventral, whereas the dorsal margin is more strongly convex than the ventral margin and is weakly inflated at the centre. The ends are obtusely rounded and slightly protracted. The length is 52.5–53.7 µm, and the width is 12–13.5 µm. The central area is indistinct. The axial area is narrow to moderately broad. 4 small stigmata are present, slightly separated from the ventral striae. The raphe is on the median axis of the valve, and is slightly displaced ventrally. Striae number 8–10 per 10 µm and are weakly radiate, becoming parallel at the ends.

Habitat: pool, river; Microhabitat: Epiphytic; Location: Chumthang Hot Springs, Ladakh

Cymbella alpestris Krammer 2002, Fig. 5 (167–170)

Ref. Krammer, 2002 (p. 52, 63; pl. 33: 1–13, pl. 34: 1–7), Bahls and Luna, 2018 (Figs. 19–21)

The valve is asymmetrical to the apical axis. The dorsal margin is strongly convex; the ventral margin is slightly concave, with slightly median inflation. The apices are broadly rounded. The length is 35.5–56.8 µm and the width is 10–12.1 µm. The central area is not distinctly differentiated from the axial area; the axial area is narrow. The strongly lateral raphe becomes filiform near the distal ends and reverse-lateral near the proximal ends. There are no isolated stigmata in the centre. Striae number 8–9 per 10 µm and are radiate throughout the valve.

Habitat: lake, river; Microhabitat: Epiphytic, Epilithic; Location: Tso Kar Lake, Leh; Hunder, Nubra Valley; Shey-Chuchot Road, Indus River; Mathoo Road near Husainiya Chuchot Gongma; Stakna Bridge

Encyonema silesiacum (Bleisch) D.G.Mann 1990, Fig. 5 (171–173)

Ref. Round et al., 1990 (p. 667); Krammer, 1997a. (p. 75; pl. 4: 1–18, pl. 7: 1, 2, 6–19), Kulikovskiy et al., 2016 (p. 188; pl. 109: 1–5)

The valve is strongly dorsiventral and semi-lanceolate. The dorsal margin is strongly convex. The ventral margin is weakly concave. The ends are narrower to more widely rounded, and are not protracted. The length is 35.1–53.7 µm and the width is 11.2–12.5 µm. The axial area is narrow and is strongly displaced ventrally. The central area is vacant, with 1–2 stigma.

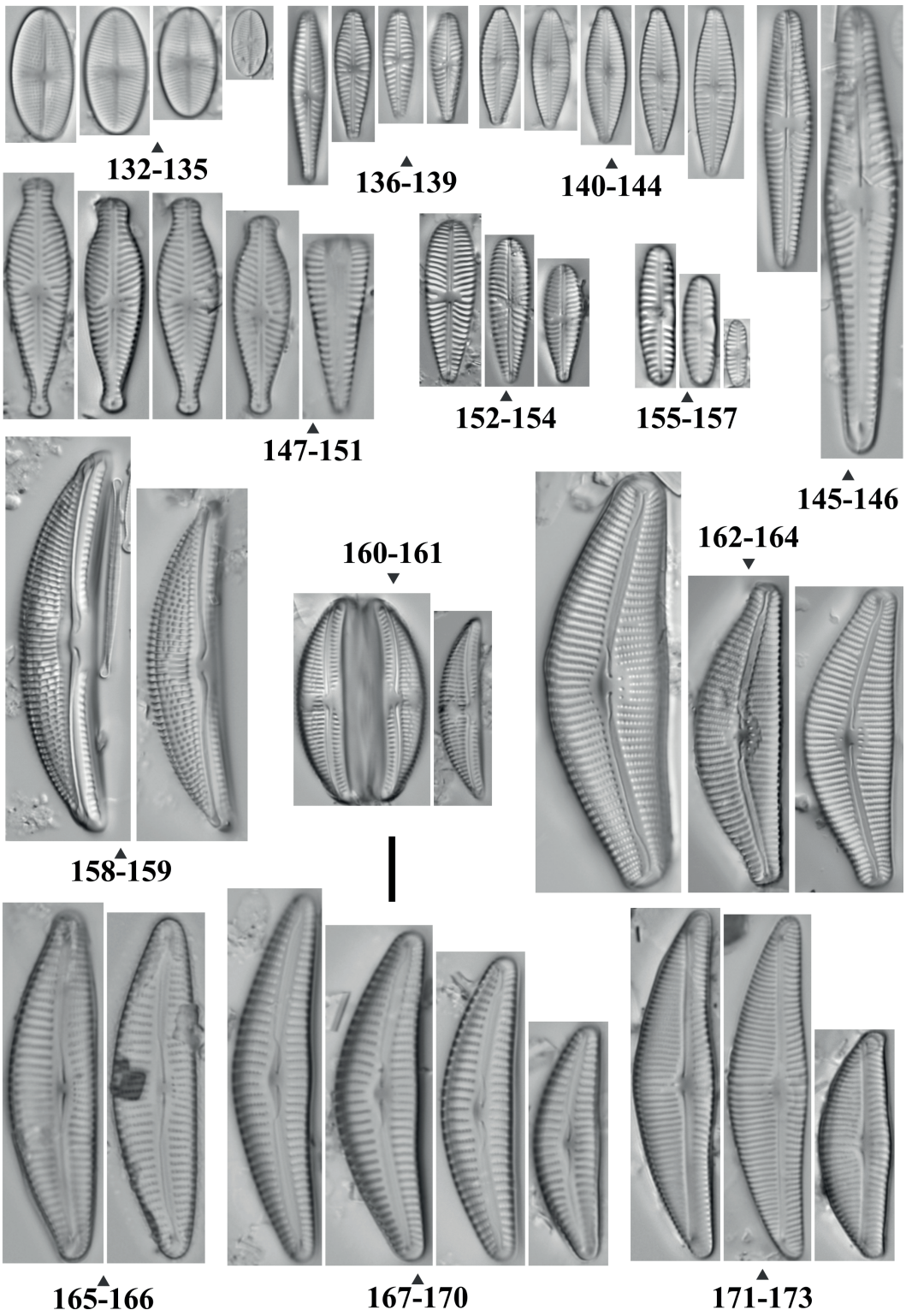

Figure 5

132-135. *Psammothidium bioretii*; 136-139. *Gomphonema minutum*; 140-144. *G. parvulum*; 145-146. *Gomphonella* cf. *qii*; 147-151. *Gomphosinica hedinii*; 152-154. *Gomphonella* cf. *olivacea*; 155-157. *Reimeria sinuata*; 158-159. *Amphora ovalis*; 160-161. *A. copulata*; 162-164. *Cymbella nepalensis*; 165-166. *C. lange-bertalotii*; 167-170. *C. alpestris*; 171-173. *Encyonema silesiacum*. **Scale bar = 10µm**

The raphe is filiform with dorsally curved central ends. Striae number 9–11 per 10 µm, are slightly radiate and converge clearly only ventrally near the ends.

Habitat: stream, river; Microhabitat: Epilithic; Location: Gya Village; Stakna Bridge, Indus River

Encyonema ventricosum (C.Agardh) Grunow 1875, Fig. 6 (174–178)

Ref. Lange-Bertalot et al., 2017 (p. 209; pl. 89: 18–22). Kulikovskiy et al., 2016 (p. 188; pl. 110: 1–5)

The valve is strongly dorsiventral and semi-lanceolate; the dorsal margin is strongly convex, and the ventral margin is weakly concave with an inflated centre. The length is 21–25 µm and the width is 6.8–7.5 µm. The ends are short, capitate and inclined ventrally. The central area is vacant, and the axial area is narrow and linear. The raphe is filiform with dorsally curved central ends; terminal fissures are turned ventrally. Distinct isolated stigma is present in the central area. Striae number 14–15 per 10 µm and radiate throughout the valve.

Habitat: stream; Microhabitat: Epilithic, Epiphytic; Location: Indus River, Leh; Tiri Village; Tso Moriri Lake, Ladakh; Mughalpura, Srinagar-Leh Highway

Encyonopsis cesatii (Rabenh.) Krammer 1997, Fig. 6 (179–181)

Ref. Krammer, 1997 (p. 156, 152; pl. 182: 1–13, pl. 183: 10–12); Lange-Bertalot et al., 2017 (p. 211; pl. 91: 1–17); Kulikovskiy et al., 2016 (p. 193; pl. 111: 15–20)

The valve is slightly dorsiventral, lanceolate. Dorsal and ventral margin moderately convex. Ends narrow and subrostrate. The length is 46.2–66.8 µm and the width is 6.0–8.1 µm. The central area is vacant or with hints of shortened striae. The axial area is linear and very narrow. The raphe is slightly undulate, the central ends turn dorsal, and the terminal fissures are comma-shaped and are curved towards the ventral side. Striae number 16–20 per 10 µm and are slightly parallel and radiate.

Habitat: river; Microhabitat: Epiphytic; Location: Hunder, Nubra Valley

Encyonopsis microcephala (Grunow) Krammer 1997, Fig. 6 (182, 183)

Ref. Krammer, 1997 (p. 91; pl. 143: 1, 4, 5, 8–26; pl. 146: 1–5); Lange-Bertalot et al., 2017 (p. 213; pl. 91: 35–17); Kulikovskiy et al., 2016 (p. 194; pl. 111: 38–40)

The valve is symmetrical to weakly dorsiventral, linear to linear-elliptical. The ends are narrowly capitate. The length is 14.3–18.7 µm and the width is 3.1–4.3 µm. The central area is variable, shortened by the central striae. The axial area is very narrow and linear without expansion towards the centre. The raphe is filiform. Striae number 22–26 per 10 µm and are weakly radiate throughout the valve.

Habitat: lake; Microhabitat: Epiphytic, Epilithic; Location: Tso Moriri Lake, Ladakh; Shey-Chuchot Road, Indus River; Husainiya Chuchot Gongma; Stakna Bridge, Indus River

Epithemia turgida (Ehrenb.) Kutz.1844, Fig. 6 (184–186)

Ref. Kutzing, 1844 (p. 34; pl. 5: 14); Vishnyakov et al., 2014 (p. 326; pl. 325: f–l); Lange-Bertalot et al., 2017 (p. 221; pl. 122: 1–4); Karthick et al., 2013 (p. 105; pl. 105: 1–5)

The valve is dorsiventral, tapering towards the ends. The ends are rounded to slightly capitate. The dorsal margin is strongly convex and the ventral margin is slightly concave. The length is 55–65 µm and the width is 9.9–12.1 µm. The raphe canal abuts the ventral margin at the distal ends of the valve and arches towards the dorsal margin in the valve centre. Striae number 10–12 per 10 µm and the costae are mostly 4 per 10 µm.

Habitat: river; Microhabitat: Epilithic and Epiphytic; Location: Indus River, Leh and Shey-Chuchot Road, Indus River

Epithemia proboscidea Kütz. 1844, Fig. 6 (187–189)

Ref. Kützing, 1844 **(**p. 35; pl. 5: 13); Vishnyakov et al., 2014 (p. 321; 6)

The valve is linear with a convex dorsal margin and a weakly concave ventral margin. The apices are narrow and truncate to capitate. The length is 50.6–65 µm, and the width is 9.8–11.2 µm. Raphe runs almost straight atop or closely above the ventral edge, dorsally in the centre, however without reaching the median line of the valve. Striae number 12–14 per 10 µm. The costae number 4 per 10 µm and are parallel to slightly radiate and are often irregularly arranged.

Habitat: river, Microhabitat: Epilithic; Location: Indus

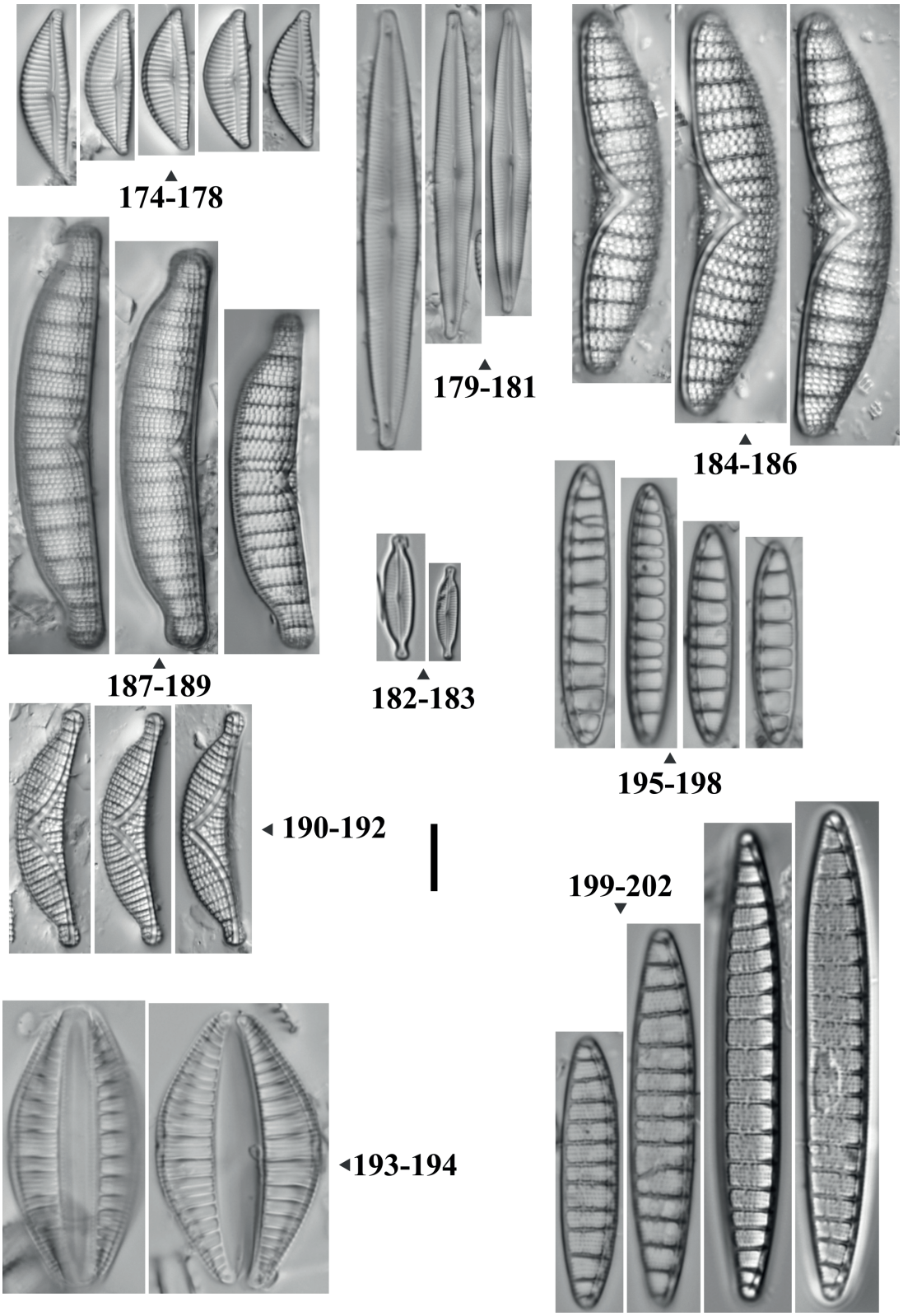

Figure 6

174-178. *Encyonema ventricosum;* 179-181. *Encyonopsis cesatii*; 182-183. *E. microcephala*; 184-186. *Epithemia turgida*; 187-189. *E. proboscidea*; 190-192. *E. sorex*; 193-194. *Rhopalodia gibberula*; 195-198. *Denticula valida*; 199-202. *Denticula thermaloides*. **Scale bar = 10µm**

River, Leh

Epithemia sorex Kütz. 1844, Fig. 6 (190–192)

Ref. Kützing, 1844 (p. 33; pl. 5: a–c); Lange-Bertalot et al., 2017 (p. 220; pl. 123: 1–7); Karthick et al., 2013 (p. 104; pl. 104: 5); Patrick & Reimer, 1975 (p. 188; pl. 27: 4)

The valve is strongly to moderately-dorsiventral. The dorsal margin is usually strongly convex, and the ventral margin is moderately concave. The ends are more or less differentiated and capitate. The length is 35.2–35.6 µm and the width is 6.7–6.8 µm. The raphe is strongly curved, rising dorsally almost near the valve margin in the centre and reaching the apex of the drawn-out ends. Costae number 4 per 10 µm and striae number 12–14 per 10 µm and are radiate throughout the valve.

Habitat: river; Microhabitat: Epilithic and Epiphytic; Location: Indus River, Leh and Stakna Bridge

Rhopalodia gibberula (Ehrenb.) O.Müll. 1895, Fig. 6 (193, 194)

Ref. Müller, 1895 (p. 58; pl. 2), John, 2016 (p. 147; pl. 340: H, I)

The valve is strongly dorsiventral and is claw-like in shape. The dorsal margin is strongly convex with a slight but noticeable indentation in the middle. The ventral margin is more or less straight. The apices are bent ventrally, sometime slightly protracted and rounded ventrally deflected. The length is 41.2–43.1 µm and the width is 6–7.5 µm. The raphe canal follows the dorsal margin. The raphe is supported by fibulae. Striae number 14–16 per 10 µm, and the fibulae number 3–4 per 10 µm.

Habitat: lake; Microhabitat: Epiphytic; Location: Tso Kar Lake.

Denticula valida (Pedicino) Grunow 1885, Fig. 6 (195–198)

Ref. Van Heurck, 1885 (pl. 49: 5), Hamsher et al., 2014 (p. 353; pl. 354: A)

The valve is lanceolate to linear with convex to parallel sides with the raphe side often having a slight constriction and rounded acute apices. The length is 30–43 µm and the width is 6–7.1 µm. Striae are parallel in the centre to slightly convergent at the apices, but are evenly spaced throughout the valve. Striae number 20–22 per 10 µm. The canal raphe is eccentric with no obvious keel; fibulae number 3–4 per 10 µm, extending across the transapical axis.

Habitat: stream and pool; Microhabitat: Epiphytic; Location: Chumthang Hot Springs, Ladakh

Denticula thermaloides Van de Vijver & Cocquyt 2009, Fig. 6 (199–202)

Ref. Van de Vijver & Cocquyt, 2009 (p. 217–219; 56–74).

The valve is linear to lanceolate with convex to parallel margins and acutely rounded apices. The valve length is 42.0–75.0 µm and the width is 8.6–9 µm. The raphe is strongly displaced towards the margin. Fibulae number 3–4 per 10 µm, are fairly broad and parallel, extending across the transapical axis throughout the valve. A large, double-topped hump is present in the centre of each costa, covering almost half of the costa. The Striae are parallel and evenly spaced throughout the valve. Striae number 12–16 per 10 µm. The canal raphe is eccentric. Puncta are not visible in LM.

Habitat: stream and pool; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh

Nitzschia commutata Grunow 1880, Fig. 7 (203–205)

Ref. Witkowski et al., 2000 (p. 375; pl. 195: 3–5); Stenger-Kovács and Lengyel, 2015 (p. 120; pl. 56: 1–15)

The valve is slightly arcuate with one margin slightly convex and the other slightly concave. The concave margin recurves near the apices to form capitate apices. The length is 47.1–82.1 µm and the width is 6.1–7.6 µm. Striae number 16–22 per 10 µm, are almost parallel in the centre and converge near the apices. Fibulae number 7–8 per 10 µm, and those in the central part are more spaced than the others.

Habitat: stream and river; Microhabitat: Epiphytic and Epilithic; Location: Chumathang Hot Springs, Ladakh, and Husainiya Chuchot Gongma

Nitzschia palea (Kutz.) W. Sm. 1856, Fig. 7 (206–208)

Ref. Smith, 1856 (p. 89), Bey & Ector, 2013 (p. 1064; pl. 1065: 1–33), Bishop et al., 2017 (pl. 138: 27–30); Ivanov et al., 2006. (pl. 181: 5–7)

The valve is linear-lanceolate to lanceolate with rostrate to sub-capitate apices; the margins are parallel in the centre. The length is 37.8–49.4 µm and the width

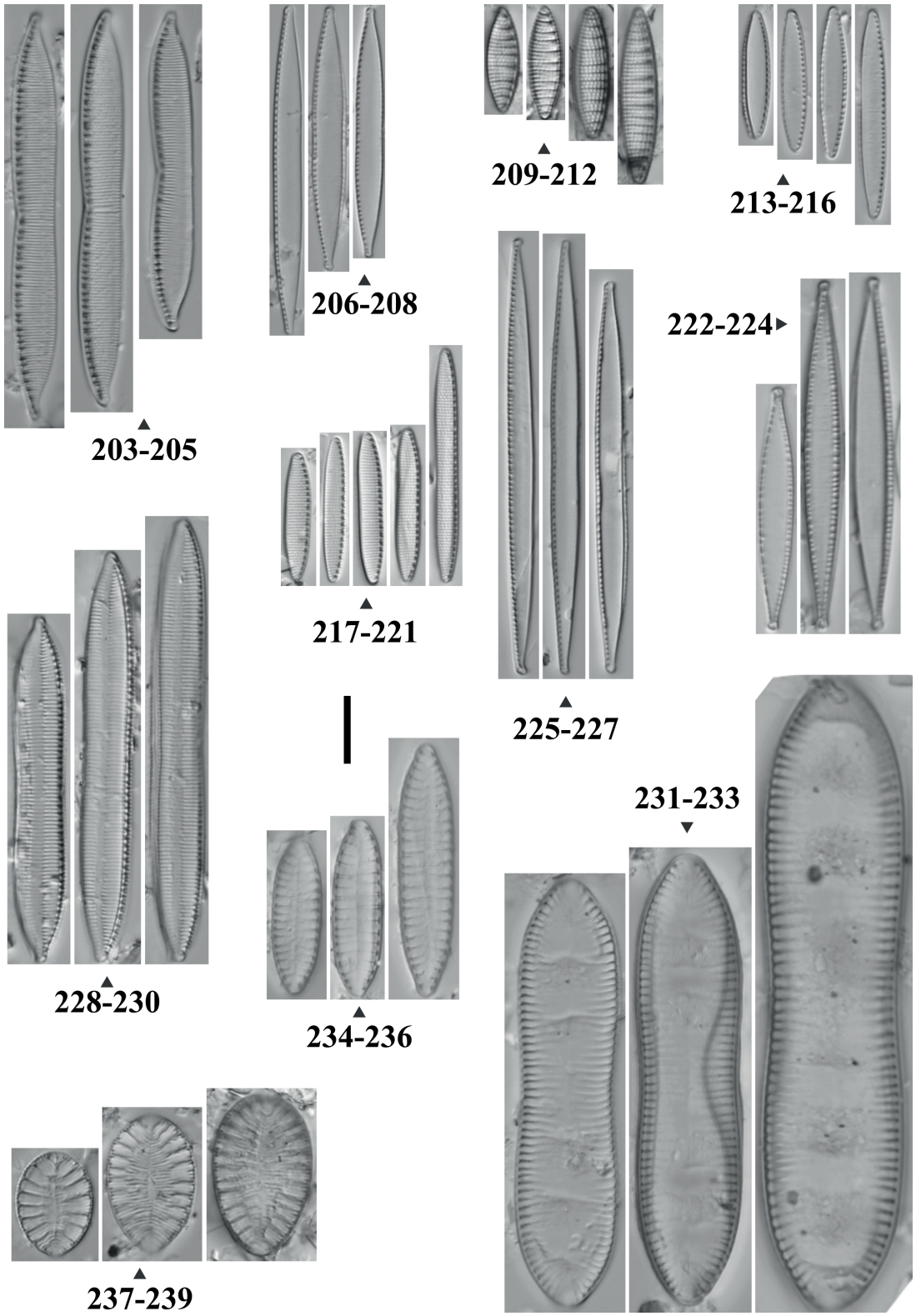

Figure 7

203-205. *Nitzschia commutata*; 206-208. *Nitzschia palea*; 209-212. *N. denticula*; 213-216. *N. pusilla*; 217-221. *N. hantzschiana*; 222-224. *N. puriformis*; 225-227. *N. paleaeformis*; 228-230.*Tryblionella hungarica*; 231-233. *Cymatopleura apiculata*; 234-236. *Surirella angusta*; 237-239. *Surirella brebissonii*. **Scale bar = 10µm**

is 3.8–4.1 µm. The transapical striae are very delicate and difficult to resolve with LM. Fibulae number 11–12 per 10 µm, and the central ones are equidistantly spaced.

Habitat: pool, pond, river, stream; Microhabitat: Epiphytic, Epilithic; Location: Chumathang Hot Springs, Ladakh; Guphunks Spituk, Leh; Indus River; Tiri Village; Stakna Bridge

Nitzschia denticula Grunow 1880, Fig. 7 (209–212)

Ref. Cleve & Grunow, 1880 (p. 82); Lange-Bertalot et al., 2017 (p. 440; pl. 119: 26–31); Kulikovskiy et al., 2016 (p. 401; pl. 145: 22–25), Tuji, 2016 (pl. 21, 22: 1–6)

The valve is lanceolate, with acutely rounded apices. The length is 16.7–26.6 µm and the width is 4.5–5.5 µm. Striae number 18–19 per 10 µm and are distinctly punctate and parallel. Fibulae number 6–7 per 10 µm and continue in transapical partitions throughout the valve.

Habitat: stream, pool and lake; Microhabitat: Epiphytic, Epipsamic; Location: Chumathang Hot Springs, Ladakh; Tso Moriri Lake; Shey-Chuchot Road, Indus River

Nitzschia pusilla Grunow 1862, Fig. 7 (213–216)

Ref**.** Grunow, 1862 (p. 579; pl. 28: 11); Lange-Bertalot et al., 2017 (p. 454; pl. 114: 10–15), Trobajo et al., 2011 (p. 85; pl. 85: 6); Bey & Ector, 2013 (p. 1072; pl. 1073: 1–28)

The valve is linear-lanceolate to linear, often elliptical. The ends are obtusely to broadly rounded, and are weakly drawn out in large specimens. The length is 19.3–31.3 µm and the width is 3.7–4 µm. Striae are not visible in LM. Fibulae number 11–13 per 10 µm, and the central ones are equidistantly spaced.

Habitat: pond; Microhabitat: Epiphytic; Location: Guphuks, Spituk, Leh.

Nitzschia hantzschiana Rabenhorst 1860, Fig. 7 (217–221)

Ref. Lange-Bertalot et al., 2017 (p. 446; pl. 114: 55–59)

The valve is linear to lanceolate with gentle tapering to a pointed or obtusely rounded end. The length is 19.3–35.4 µm and the width is 3.3–3.7 µm. Fibulae number 10–12 per 10 µm and are distinct and equidistant. Striae number 22–24 per 10 µm, are coarse, and appear distinctly punctate with LM.

Habitat: stream, pond; Microhabitat: Epiphytic and Epipsamic; Location: Chumthang Hot Springs, Ladakh; Guphunks, Spituk, Leh; Shey-Chuchot Road, Indus River

Remarks: This species is very similar to *N. valdecostata* in valve outline, but differs in number of striae and fibulae.

Nitzschia puriformis Hlúbiková & Ector 2009, Fig. 7 (222–224)

Ref. Hlúbiková et al., 2009 (p. 751: a–p)

The valve shape is lanceolate with concave valve margins that can be briefly parallel in the largest specimens. The valve apices are slightly protracted sub-capitate to capitate. The length is 36.8–53.2 µm and the width is 4.9–5.7 µm. The raphe is positioned on a distinct raphe keel, continuous from pole to pole. Striae are not visible in LM. Fibulae number 12–14 per 10 µm.

Habitat: stream and river; Microhabitat: Epilithic and Epiphytic; Location: Tso Moriri Lake, Ladakh; Stakna Bridge, Indus River

Nitzschia paleaeformis Hustedt 1950, Fig. 7 (225–227)

Ref. Lange-Bertalot et al., 2017 (p. 453: pl. 113: 48–51)

The valve is linear to linear-lanceolate. The ends are tapered, sub-capitate. The length is 59.0–65.6 µm and the width is 3.4–4.1 µm. Striae are not visible in LM. Fibulae number 10–14 per 10 µm.

Habitat: pond, river, stream; Microhabitat: Epiphytic, Epilithic, Epipsammic; Location: Chumathang Hot Springs, Ladakh

Tryblionella hungarica (Grunow) Freng. 1942, Fig. 7 (228–230)

Ref. Frenguelli, 1942 (p. 178; pl. 8: 12); Lange-Bertalot et al., 2017 (p. 598; pl. 106: 3–7); Bertolli et al. 2020 (p. 6; pl. 5: d–f); Abdel-Aal & Mofeed , 2015 (pl. 42; 1)

The valve is linear, cuneate at the poles, slightly concave in the middle. The apices are rostrate and weakly protracted. The length is 52.4–68.6 µm and the width is 7–7.5 µm. Striae number 17–18 per 10 µm. The impression of a hyaline area is created by a depression on the valve surface.

Habitat: stream, pool; Microhabitat: Epiphytic, Epilithic;

Location: Chumathang Hot Springs, Ladakh; Tiri Village, Leh; Husainiya Chuchot Gongma.

Cymatopleura apiculata W.Sm. 1853, Fig. 7 (231–233)

Ref. Smith, 1853 (p. 37; pl. 10: 79); Kulikovskiy, M. et al., 2016 (p. 412; pl. 155: 2–4); Lange-Bertalot et al., 2017 (p. 154; pl. 127: 1–4); Lange-Bertalot & Krammer, 1987 (pl. 50: 2–3)

The valve is broadly linear with a central slight constriction and tapering to blunt ends. The length is 64.3–95.0 µm and the width is 14.0–19.0 µm. A canal raphe runs around the valve margin. Fibulae number 7–9 per 10 µm. The undulations of the valve face are transapical corrugations and occur throughout the valve.

Habitat: pool; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh.

Surirella angusta Kütz. 1844, Fig. 7 (234–236)

Ref. Kützing, 1844 (p. 61; pl. 30: 52), Lange-Bertalot et al., 2017 (p. 582; pl. 133; 1–5); Kulikovskiy et al., 2016 (p. 414; pl. 164: 8–11); John, 2016 (p. 150; pl. 349: c)

The valve is linear, isobilateral and isopolar with cuneate apices. The length is 24.1–38.7 µm and the width is 7.2–8.1 µm. The central area is narrow and linear. Alar canals (marginal costae) number 7–8 per 10 µm, are parallel, and radiate towards the apices. The valve surface is finely striated.

Habitat: river, stream; Microhabitat: Epilithic, Epiphytic; Location: Indus River, Leh; Tiri Village, Leh, Stakna Bridge

Surirella brebissonii Krammer & Lange-Bert. 1987, Fig. 7 (237–239)

Ref. Krammer, K., & Lange-Bertalot, H., 1987 (p. 82; pl. 84: 21–33); Lange-Bertalot et al., 2017 (p. 583; pl. 132: 11–21)

The larger of the valves are linear-ovate, whereas the smaller valves are ovate, and smallest valve is broadly elliptical to nearly round. The length is 15.6–25 µm and the width is 12–15.1 µm. In large forms, one end is rounded in cuneate fashion and the other is broadly rounded. In smaller forms, both ends are almost equally rounded. Striae density is 18–24 per 10 µm and costa are 6–7 per 10 µm.

Habitat: pool; Microhabitat: Epiphytic; Location: Chumathang Hot Springs, Ladakh

4. Discussion

The present study is a preliminary investigation of the diatom assemblages from high-altitude water bodies and hot springs in Ladakh. This paper represents the commonly occurring diatom taxa that are observed in this region. Due to the lack of physiochemical parameters gathered at the time of collection, we predict the characteristics of the localities based on the autecology of the diatoms that are predominant in the samples.

Ladakh is a biome that offer a wide range of pristine environmental conditions, including glacial deposits, arid regions, dune fields, hot springs and saline lakes (Pandey et al. 2020). With such extremes at high altitudes, the diatom biodiversity is significantly high yet is not very well-studied. In the past, few studies were conducted on the diatoms of selected lakes and rivers in Ladakh and its adjoining region (Compère 1983, Kant & Gupta 1998, Kumar et al. 2012, and Phartiyal et al. 2020). The earliest record of diatoms from the high elevations of the Eastern Himalayas at altitudes of 2900–4200 amsl reported 51 species of diatoms. Among these, 30 taxa were new reports from India (Suxena et al. 1972). Over the years, with advancements in microscopic technology, researchers have expanded their explorations to investigate diatoms inhabiting rare habitats, including mountain lakes. Notably, the identification of diatom species has advanced to incorporate the use of electron microscopy. Recently, three lakes from high-altitude were studied for diatom diversity in the lake's littoral area, where diatom assemblages were compared along the seasonal variations and different benthic substrata (Jüttner et al. 2021). The diatoms in high mountain streams of the Alps and the Himalayas are reported to be abundant at an altitude of 4,697 amsl (Cantonati et al. 2001). Hausburg Tarn, a glacial lake on Mount Kenya, reported 57 specific and infraspecific taxa, with *Achnanthidium minutissimum* and *A. affine* as the most abundant taxa (Cocquyt 2007). The present investigation shows the dominance of *Reimeria sinuata* (Gregory) Kociolek & Stoermer 1987, revealing the affinity of this taxon for high-altitude.

The commonly-occurring diatom species across samples from various sites in Ladakh are *Fragilaria vaucheriae, Gomphonella* cf. *olivacea, Reimeria sinuata, Encyonema ventricosum,* and *Lindavia biswashanti*. In comparison, the hot springs of Ladakh represent similar diatom assemblages as observed in hot springs

from various parts of the world. The significant diatoms recorded from the hot springs of Ladakh are *Surirella brebissonii, Rhopalodia gibberula, Navicula cincta, Navicula radiosa, Anomoeoneis sphaerophora, Gogorevia exilis*. A similar assemblage including the taxa *Gogorevia exilis, Amphora ovalis*, *Anomoeoneis sphaerophora*, *Gomphonema parvulum*, *Nitzschia palea*, *Rhopalodia gibberula*, and *Ulnaria ulna* was recorded from the hot springs of northern Thailand (Nikulina & Kociolek 2011, Pumas et al. 2018). Also, Ladakh Hot springs diatoms show 15 typical diatoms reported in the geothermal diatoms from Altiplano, Chile (Angel et al. 2018), namely, *Gogorevia exilis, Denticula thermaloides, Denticula valida, Encyonopsis microcephala, Fragilaria vaucheriae, Gomphonema parvulum, Navicula cincta, Navicula gregaria, Navicula tripunctata, Nitzschia palea, Nitzschia pusilla, Pseudostaurosira brevistriata, Surirella angusta, Tryblionella hungarica* and *Ulnaria ulna*. Furthermore, occurrence of *Nitzschia palea* across the five sampling sites may indicate elevated nutrients levels, likely attributable to some kind of human impact on these sites, and further observation combined with water chemistry measurements is required to ascertain the anthropogenic effects (Van Dam et al. 1994, Watanabe et al. 2005).

The species *Gogorevia exilis* is known to be dominant in high-altitude warm hydrothermal ponds (thermals) in a tectonically active region (Cabrol et al. 2016). Also, *Gogorevia exilis* was predominant in the Hot springs of Oyasukyo Gorge, Japan, and in Hot springs in Northern Thailand (Watanabe et al. 2011, Pumas et al. 2018). Correspondingly, hot springs in Ladakh also showed a high occurrence of *Gogorevia exilis*. *Denticula thermaloides* Van de Vijver & Cocquyt was recorded in the high temperature (80°C) waters of the La Calera Hot Springs, Peru Likewise, the current study recorded the presence of *Denticula thermaloides* Van de Vijver & Cocquyt at 80°C. Consequently, the diatom assemblages analyzed in this study also depict the diatom populations found in high-altitude environments and hot springs habitats.

5. Conclusion

The study of diatom diversity from one of the highest mountain ranges in the Western Himalayas – Ladakh resulted in the identification of 74 diatom taxa. This study has documented the taxonomy, characteristics, and biodiversity of the commonly-occurring diatoms in the high-altitude rivers, streams, lakes, and hot springs of the Ladakh region. Focusing these different habitats in this region, we concluded that the common species of high-altitude hot springs habitats were *Gogorevia exilis* and *Denticula thermaloides*, whereas the other most-commonly occurring species in stream, river and lake habitat were *Reimeria sinuata, Fragilaria vaucheriae, Gomphonella* cf. *olivacea, Encyonema ventricosum, Lindavia biswashanti, Diatoma moniliformis,* and *Denticula valida*. Although the present report focuses only on the most-commonly-occurring diatom taxa, the entire flora will be presented in upcoming publications.

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