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Gomphonema Species (Bacillariophyceae) from Marikina River, Rizal (Luzon), Philippines

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A floristic study of the diatoms (Bacillariophyceae) along the Marikina River in the eastern part of Metro Manila, Philippines, recorded at least 140 species belonging to 39 genera. Of these genera, one of the greatest number of species was observed in the genus *Gomphonema* (18 species). These species were identified and described under the bright field light microscope. Some species were further observed under the scanning electron microscope. A habitat description of the occurrence of the *Gomphonema* species is given. Twelve (12) out of the 18 species are new records for the country: *G. brasiliense* subsp. *pacificum* Moser, Lange-Bertalot & Metzeltin, *G. chinense* Liu & Kociolek, *G. contraturris* Lange-Bertalot & E.Reichardt, *G. cuneolus* E.Reichardt, *G. exilissimum* (Grunow) Lange-Bertalot & E.Reichardt, *G. insigniforme* E.Reichardt & Lange-Bertalot, *G. javanicum* Hustedt, *G. kobayasii* Kociolek & J.C.Kingston, *G. pseudosphaerophorum* H. Kobayasi, *G. sundaense* E.Reichardt, *G.* cf. *qingyiensis* L-X Zhang, P. Yu & Q-M You, and *G. vibrio* var. *bohemicum* (Reichelt & Fricke) R. Ross. Hence, this paper reports a total of 44 species of *Gomphonema* from the Philippines, including previous studies from 1937 to date.

Keywords: biraphid and heteropolar diatoms, *Gomphonema parvulum*, habitat description, river, taxonomy

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INTRODUCTION

Diatoms are considered very useful indicators of environmental changes, including acidification, eutrophication, and climate change (Wojtal 2003). The periphytic diatom species are especially important indicators of water quality because they respond directly to nutrients and can be more stable indicators of trophic state than measurements of nutrient concentration such as chlorophyll a (Belton *et al.* 2005). In fact, several diatom indices have been developed for the estimation of water quality like the trophic diatom index (Kelly and Whitton 1995) and the pollution index (Descy 1979). The importance of diatoms lies also in their universality in occurrence.

One of the most common benthic diatom genera is the genus *Gomphonema.* It is well-adapted to flowing waters due to the presence of branched mucilaginous stalks that attach them to some substrates (Round *et al.* 1990). *Gomphonema* Agardh is a large genus, with over of about 400 taxa (van Landingham 1978), and of worldwide distribution. Its species are a major component of freshwater ecosystems like in river systems as phytoplankton (Salleh and Rahim 1994; Lu *et al.* 2020) and as benthic assemblages (Wan Maznah and Mansor 2000, 2002; Omar 2010; Venkatachalapathy and Karthikeyan 2013; Khan 2015; Heinrich *et al.* 2019; Al Falah *et al.* 2023). Omar (2010) indicated that *G. acuminatum* was considered a clean water species in his survey of Malaysian freshwater ecosystems, whereas *G. parvulum* was considered a pollution-tolerant species in Pinang River in Malaysia (Wan Maznah and Mansor 2002). The species showed a negative relationship with dissolved oxygen (DO) but a positive relationship with other parameters such as BOD (biological oxygen demand), COD (chemical oxygen demand), conductivity, ammonium-N, nitrate-N, PO_4–P, alkalinity, TDS, TS, and TSS. This species was also considered a eutrophic indicator during warm seasons in the Lalin River in northeast China (Lu *et al.* 2020). Whereas in the Cauvery River in South India, it was observed that aside from *G. parvulum*, another *Gomphonema* species (*G. lanceolatum*) was observed in highly polluted waters (Venkatachalapathy and Karthikeyan 2013).

One of the earliest observed species of *Gomphonema* in the Philippines was done in 1937 by B.V. Skvortzow (Skvortzov) from the water samples of the water filtration facility in Balara, Quezon City (Appendix I). Of the 60 taxa that he described, only one species of *Gomphonema* was noted (*G. lanceoloatum* C. Agardh). However, the currently valid name of this species is *Brebissonia lanceolata* (C. Agardh) R. K. Mahoney & Reimer (Guiry and Guiry 2023). In fact, most of the earlier diatom studies in the country were done by foreign scientists (Skvortzow 1937; Woltereck 1941; Hustedt 1942; Podzorski and Håkansson 1987; Antoine *et al.* 1997). Although the first compendium of diatoms in the Philippines was done in 1925 by Albert Mann, this was mainly composed of marine types that did not include any *Gomphonema* species. The greatest number of taxa in *Gomphonema* that was observed and studied was 13, which was the work of Hustedt in 1942 on the Diatoms of the Indo-Malaysian Archipelago and the Hawaiian Islands. Most of the samplings he did were from lakes and ponds. Hence, no studies on diatoms of Philippine rivers have been done except in the treatise of Podzorski and Håkansson (1987), wherein samplings were done in some rivers in Palawan. Lately (2000 up to date), more attention is being given to the diatoms in relation to the water quality of rivers. For example, two rivers (Cugman and Bigaan) were studied in Cagayan de Oro City (Mindanao), but no *Gomphonema* species was noted; instead, they identified two marine diatoms [*Chaetoceros decipiens* Cleve and *Thalassionema nitzschioides* (Grunow) Mereschkowsky] (Canencia and Gomez 2016). Whereas in the same city but in Umalag River, there were 15 genera of periphytic diatoms identified, including *Gomphonema* (Malaran *et al.* 2019). Moreover, the planktonic study on Banahao-Palhi River in Leyte (Visayas) reported 34 taxa in the Bacillariophyceae, including two new records of *Gomphonema* species, *i.e. G. constrictum* var. *capitata* (Ehrenberg) Grünow and *G. subclavatum* (Grünow) Grünow (Galinato and Evangelio 2016). However, these two *Gomphonema* species had a relatively low density of abundance of 1.58 and 0.12% for *G. constrictum* var. *capitata* and *G. subclavatum*, respectively. Whereas another diatom, *Cymbella turgida*, had the highest relative density in the study area at 9.9%. Periphytic diatoms were also studied in relation to the water quality of four rivers in Indang, Cavite (Luzon) (Dimero *et al.* 2021). They identified 10 genera of diatoms but did not include *Gomphonema.* Among these studies on Philippine rivers, there was no taxonomic work done on the identified taxa of *Gomphonema*.

Therefore, so far, there has been no taxonomic study on the genus *Gomphonema* in the country. Hence, this paper presents for the first time a comprehensive taxonomy and habitat description of 18 *Gomphonema* species from Marikina River (Luzon), Philippines. This number includes 12 species that are new records for the country. This brings a total of 44 taxa of *Gomphonema* reported in the country based on previous reports from 1937 to date (Appendix I). This is a basic paper that serves as baseline information by which we can build over time. It is information that may be useful for other basic and applied studies such as in assessing the water quality of our river systems.

MATERIALS AND METHODS

The Study and Collection Sites

The Marikina River, one of the major stream networks of Laguna de Bay, is located in the north-eastern part of Rizal, with geographic coordinates of 14º50' to 14º 34' north latitude and 121º20' east longitude (Peralta *et al.* 2019). It is about 66.81 km in total length with about 698 km^2 in the watershed area. Its headwaters are near the Sierra Madre Mountains like in Rodriguez (formerly Montalban) in Rizal province and flowing down into the Pasig River (Pasig, Rizal) and empty in Manila Bay. Because it is a river system that traverses through Metro Manila, the largest urban population in the country [13 M in May 2020; PSA (2021)], it serves as the lifeblood and driver of the economy of the communities inside and outside the Marikina River basin. However, with the growing population and industrialization along the Marikina River, its water quality has been degrading as it goes downstream (RBCO-DENR 2015). The built-up areas within the watershed are mostly composed of residential, commercial, industrial, and some agricultural and forested areas. The upper portion of the river basin was protected from further urbanization by establishing the Upper Marikina River Basin Protected Landscape, with a total land area of about 261.26 km^2, through Presidential Proclamation No. 296 in 2001. Despite such presidential proclamation, human activities such as tourism, informal settlements, and deforestation still prevail in this protected area (Peralta *et al.* 2019). Based on this historical background, there were 30 sites studied and collected microalgal (diatom) samples along the Marikina River (Figure 1; Table 1). Of these sites, 57% are in the protected areas and 43% are in the unprotected region. The sites were located in any of the three different types of land uses, *i.e.* agricultural, forested, or residential. About 40% are in residential places, 33% are in forested places, and 27% are in agricultural places. There are two sites that were considered as strictly belonging to the upstream area (nos. 8 and 10), and the midstream ones are Site nos. 27 and 47, whereas the downstream sites are nos. 28 and 29. Figure 2 shows the physical features of three different collecting sites. So far, there is a lack of baseline ecological information to assess the water quality of the Marikina Watershed – including its freshwater protected area, the Upper Marikina River

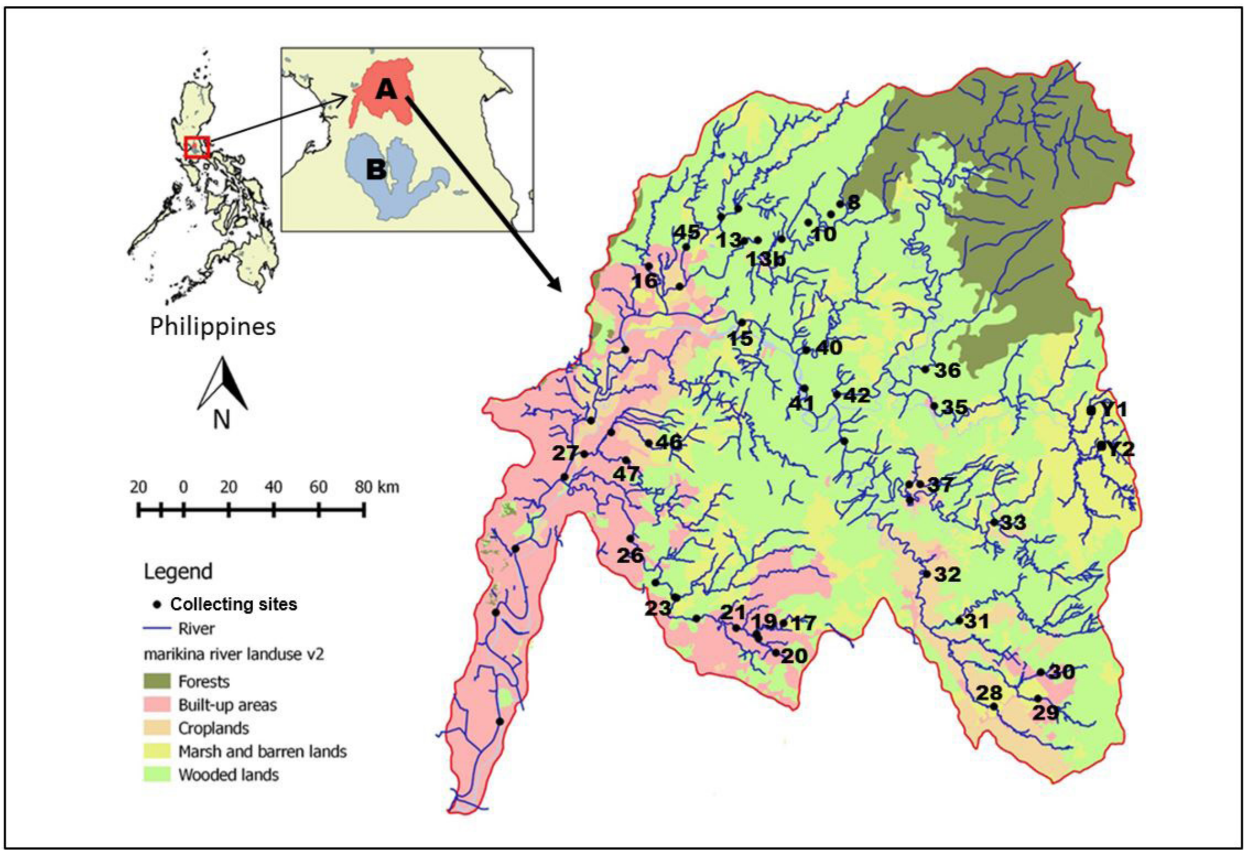


Figure 1. The collecting sites in Marikina Watershed, Rizal, Philippines. Protected sites: 8, 10, 13, 13B, 15, 28, 30, 31, 33, 35, 36, 37, 40, 41, 42, Y1, Y2; Unprotected sites: 16, 17, 19, 20, 21, 23, 26, 27, 29, 32, 45, 46, 47. [A] Marikina Watershed [B] Laguna de Bay [●] collecting sites are numbered except Y1 and Y2

Table 1. The collecting sites in Marikina River, Rizal, Philippines, their land use, protection status (protected or unprotected), and stream reach system in October–November 2016.

No.	Site identification	Land use	Protection status	Stream reach system (*sensu stricto*)
1	8	Forested	Protected	Upstream
2	10	Forested	Protected	Upstream
3	13	Agricultural	Protected	
4	13B	Forested	Protected	
5	15	Residential	Protected	
6	16	Residential	Unprotected	
7	17	Residential	Unprotected	
8	19	Residential	Unprotected	
9	20	Residential	Unprotected	
10	21	Residential	Unprotected	
11	23	Residential	Unprotected	
12	26	Residential	Unprotected	
13	27	Residential	Unprotected	Midstream
14	28	Agricultural	Protected	Downstream
15	29	Agricultural	Unprotected	Downstream
16	30	Agricultural	Protected	
17	31	Agricultural	Protected	
18	32	Agricultural	Unprotected	
19	33	Forested	Protected	
20	35	Forested	Protected	
21	36	Forested	Protected	
22	37	Forested	Protected	
23	40	Forested	Protected	
24	41	Forested	Protected	
25	42	Forested	Protected	
26	45	Residential	Unprotected	
27	46	Residential	Unprotected	
28	47	Residential	Unprotected	Midstream
29	Y1	Agricultural	Protected	
30	Y2	Agricultural	Protected	

Basin Protected Landscape (Peralta *et al.* 2019). Hence, this gives us the urgency in studying the baseline biotic and abiotic information of this site.

Measurement of Abiotic Parameters

Abiotic parameters were taken at three points in each site following the protocol established by Peralta *et al.* (2019). Water temperature, pH, conductivity, total dissolved solids (TDS), and salinity were taken with a hand-held multiparameter probe (EC500; Extech Instruments, NH, USA), whereas DO was measured with a DO meter (DO600; Extech Instruments, NH, USA). Water velocity was measured at each monitoring point using a flow velocity meter (fabricated at Research Institute for Humanity and Nature, Kyoto, Tokyo, Japan). Canopy cover, which serves as a proxy of riparian vegetation cover, was determined by taking digital photos (NIKON D7000, Japan) with a fish eye lens (Sigma 4.5mm F2.8 EX DC Circular Fisheye HSN, Japan), and the digital images were analyzed using CanopOn 2.0 software (http://takenaka-akio.org/etc/canopon2.0).

Figure 2. Photos showing general physical features of three different collecting sites in Marikina watershed. [A] Site 8; [B] Site 8, close-up view of algae attached to the stones; [C] Site 23; [D] Site 21. [Site 8] Rizal, Rodriguez (formerly known as Montalban), *Barangay* Puray, (one of the headwaters); [Site 21] Antipolo City, Barangay dela Paz; [Site 23] Antipolo City, *Barangay* Cupang.

Collection of Diatoms

There were 30 sites studied and collected microalgal samples, including diatoms (Figure 1). Sampling for the diatoms was done once in all 30 sites (therefore, 30 samples collected) that was conducted from October–November 2016, at a time when there was a shift from wet to dry seasons in the country. From each collecting site, benthic diatoms were scraped from the surfaces of six cobbles with an area of 36 cm^2. An aliquot of the suspension, in which epilithic algae were rinsed from the surface of cobbles with the stream water, was preserved in 1.0% formaldehyde and 0.04% glutaraldehyde, and kept in a cooler or in the refrigerator (4 ºC) (Kawanobe and Ikeya 2016).

Preparation of Diatom Samples

Preserved samples were washed with several changes of distilled water by centrifugation until no smell of the preservative is noted. The cytoplasm of the diatoms was digested chemically with the use of sulfuric acid and potassium dichromate, following the method summarized by Martinez-Goss *et al.* (2020). The digested samples were washed thoroughly with distilled water to obtain cleaned frustules. They were dehydrated with a series of increasing the concentration of ethanol and finally stored in 95% ethanol. Cleaned samples were mounted onto a permanent slide using Pleurax, a synthetic resin with a 1.73 refractive index (Martinez-Goss *et al.* 2020).

Observation and Photography of Diatoms

Morphological features of the cleaned diatoms were observed microscopically under bright-field microscopes with an oil immersion objective lens (x 100, N.A. =1.40) (Carl Zeiss Axioscope A1, Hal 100, Carl Zeiss, Gottingen, Germany and Olympus, BX 60, Tokyo, Japan).

Diatom photomicrographs were taken using a compound light microscope (BX60, Olympus, Tokyo, Japan) under an oil immersion objective lens and a digital camera (DS-Fi1, Nikon, Tokyo, Japan). They were digitized by using a flatbed scanner and adjusted to a magnification of x 2000 (375 dpi) using Photoshop Element 7 (Adobe, California, USA).

Some of the diatoms or parts of special diatoms were prepared for scanning electron microscopy by mounting them on a round cover glass (10 mm in diameter), attached to a stub and coated with palladium, observed, photographed under the scanning electron microscope (SEM, JSM6301F, JEOL, Tokyo, Japan), and operated at 5 kV.

Identification of Diatoms

The length, width, and striae density of diatom valves taken by light microscopy were measured in Photoshop Elements and converted to the original scale by dividing by 2000. Those taken by scanning electron microscopy were converted to the original size based on the scale bar displayed electronically on the picture.

Identification of the diatoms was done on the basis of morphological characters with the use of available literature on diatom taxonomy, as cited in the taxonomy of the species in this paper. All units of measurement are in micrometers (µm).

Statistical Analyses

Statistical analyses were done to compare the characteristic features of the two groups of collecting sites, *i.e.* one with observed *Gomphonema* species and the other one without observed *Gomphonema* species. One was the Student's t-test for data that satisfied normality and homogeneity of variances assumptions, and the other one was the Mann-Whitney U test for data that violated at least one of the two assumptions mentioned. A 5% level of significance was used in making conclusions.

RESULTS

Taxonomy

The genus *Gomphonema* is classified in the class Bacillariophyceae, order Cymbellales, and family Gomphonemataceae (Guiry and Guiry 2023). This means that the genus is included in the groups of *Cymbella*, *Encyonema*, *Gomphoneis*, *Reimeria*, and *Didymosphenia* (Kermarrec *et al.* 2011). However, *Gomphonema* is unique from the rest by having biraphid and asymmetrical valves or heteropolar valves, wherein one of the apices or poles is broader than the other end, usually the broader end is called the head pole and the latter or narrower end is called the foot pole. The poles may be rounded, rostrate, or capitated. In the girdle view, the cells are wedge-shaped. Valves have axial areas that may be narrow or wide. The true raphe may be straight or sinuous or straight but curved at the ends. Striae are uniseriate, occasionally biseriate (Round *et al.* 1990), usually parallel to one another becoming more radiate towards the poles. The central area may be of various shapes that may have asymmetric striae, *i.e.* one longer stria, wherein near it is usually a stigma, and opposite this is also a short stria (Round *et al.* 1990). Cells may be colonial, attached to solid substrates by means of branched mucilaginous stalks. Very common in freshwater benthic communities, although a few marine species have been reported (Round *et al.* 1990).

There were 18 *Gomphonema* species observed and described from the Marikina River and all were identified except for one species (*G.* cf. *qingyiensis*). These species are delineated from one another by means of a dichotomous key, as below.

Key to the Species of *Gomphonema* Observed from the Marikina River

1a. Head pole more or less protracted --------------------2
1b. Head pole not protracted --------------------------------10
2a. Head pole capitate* ---------------------------------------3
2b. Head pole rostrate or roundly protracted ------------5
*Smaller valves do not have clear capitate ends.
3a. Valve elliptical, less heteropolar, length less than 30 µm ---------------------------------------*G. lagenula*
3b. Valve clavate, strongly heteropolar, length more than 25 µm -- 4

4a. Head poles broadly capitate -- *G. pseudosphaerophorum*
4b. Head poles narrowly capitate ----- *G. sphaerophorum*
5a. Head poles roundly protracted ------------------------- 6
5b. Head poles rostrate ---------------------------------------7
6a. Valves linear-lanceolate, axial area wide-- *G. chinense*
6b. Valves rhombic with truncated poles, axial area narrow -------------------------*G. javanicum*
7a. Valves broader than 10 µm, strongly heteropolar --- *G. contraturris*
7b. Valves narrower than 10 µm --------------------------- 8
8a. Valve width usually less than 5 µm --*G. exilissimum*
8b. Valve width between 5µm and 10 µm -----------------9
9a. Striae denser, 12 in 10 µm or more -------*G. parvulum*
9b. Striae coarser, less than 10 in 10 µm ---*G. insigniforme*
10a. Valves rhombic to rhombic-lanceolate--------------11
10b. Valves elliptic-lanceolate, elliptic, or linear-------13
11a. Valves with wide axial area; stigma absent -------------------------*G. brasiliense* subsp. *pacificum*
11b. Axial area narrow, stigma present ------------------12
12a. Valves wider than 10 µm or longer; striae almost parallel ---*G. affine*
12b. Valves narrower than 10 µm; striae more radiate --*G. bozenae*
13a. Valves broader than 6.5 µm, with biseriate striae ---*G.* cf. *qingyiensis*
13b. Valves narrower than 6.5 µm, striae not biseriate ---14
14a. Axial area wide, head poles more rounded ---*G. sundaense*
14b. Axial area narrower, head poles more rounded ---15
15a. Axial area slightly wide------------------------------16
15b. Axial area narrow--------------------------------------17
16a. Valves elliptic, less heteropolar -------------------------------*G. vibrio* var. *bohemicum*
16b. Valves elliptic-lanceolate, more heteropolar --*G. pumilum*
17a. Head pole roundly cuneate, foot pole acutely cuneate--------------------------------------*G. cuneolus*
17b. Head pole round, foot pole obtusely cuneate--*G. kobayasii*

The Species

***Gomphonema lagenula* Kützing** Figures 3–5, 45–46

Hustedt (1942), p. 113 (as *Gomphonema parvulum* var. *lagenula*); Patrick and Reimer (1975), p. 123, Plate 17, Figure 9 (as *G. parvulum* f. *lagenula*); Johnson (2018).

Valves are elliptic; both apices are distinctly capitate, but the foot pole is more protracted than the head pole, which appears "bent"; the axial area is linear and narrow; the central area is similar to that of *G. parvulum*; *i.e.* asymmetric, where a longer stria is near a punctate stigma, and opposite this is a short stria; striae are slightly wavy-radiate reaching the raphe; there are 11–14 striae in 10 µm; valves are 11.0–25.9 µm long, 6.2–7.5 µm wide. The dimensions of the Marikina River specimens are consistent with the descriptions by Patrick and Reimer (1975) and Johnson (2018).

Distribution in the Philippines: Rizal, Navotas, (Dagat-dagatan swamp, frequent in occurrence; Hustedt 1942); Batangas, Taal (Taal Lake); Camarines Sur, Buhi (Buhi Lake, river); Oriental Mindoro, Calapan (Caluangan Lake; Hustedt 1942); MINDANAO: Lanao del Sur, Madamba (lake); Cagayan de Oro (lake); Sulu, Jolo (lake) (Hustedt 1942).

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 13, 13b, 20, 23, 26, 28, 32, 35; near residential, forested, and agricultural areas). This species was observed in these habitats with average values of 7.53, 7.51, 253.12, and 175.10 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

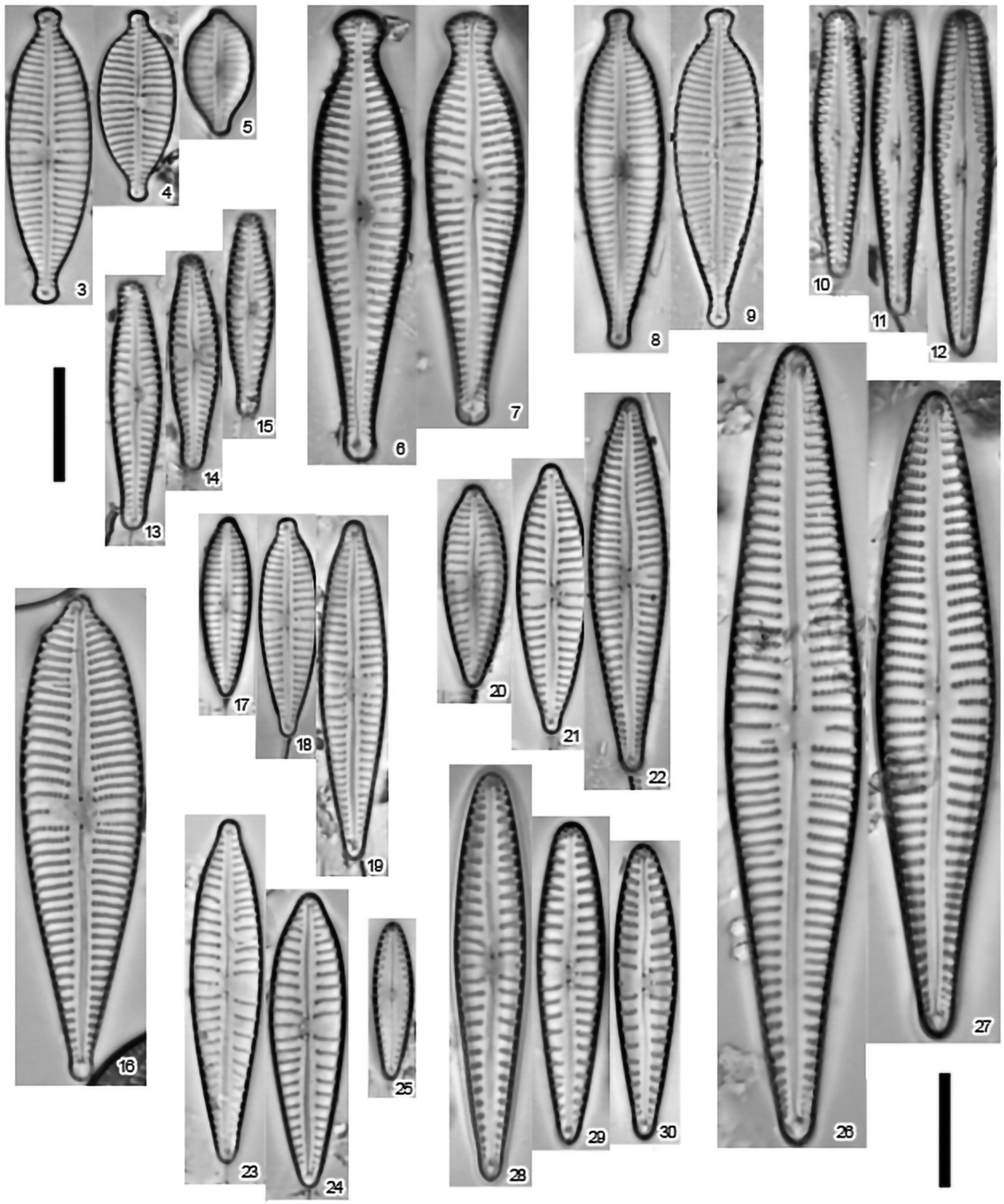
***Gomphonema pseudosphaerophorum* H.Kobayasi**
Figures 6–7, 47

Ueyama and Kobayasi (1988), p. 451, Figure 10–12, 25–37; Polaskey and Vaccarino (2016); Liu *et al.* (2021), p. 1047, Plate 5, 6, Figure 37–50.

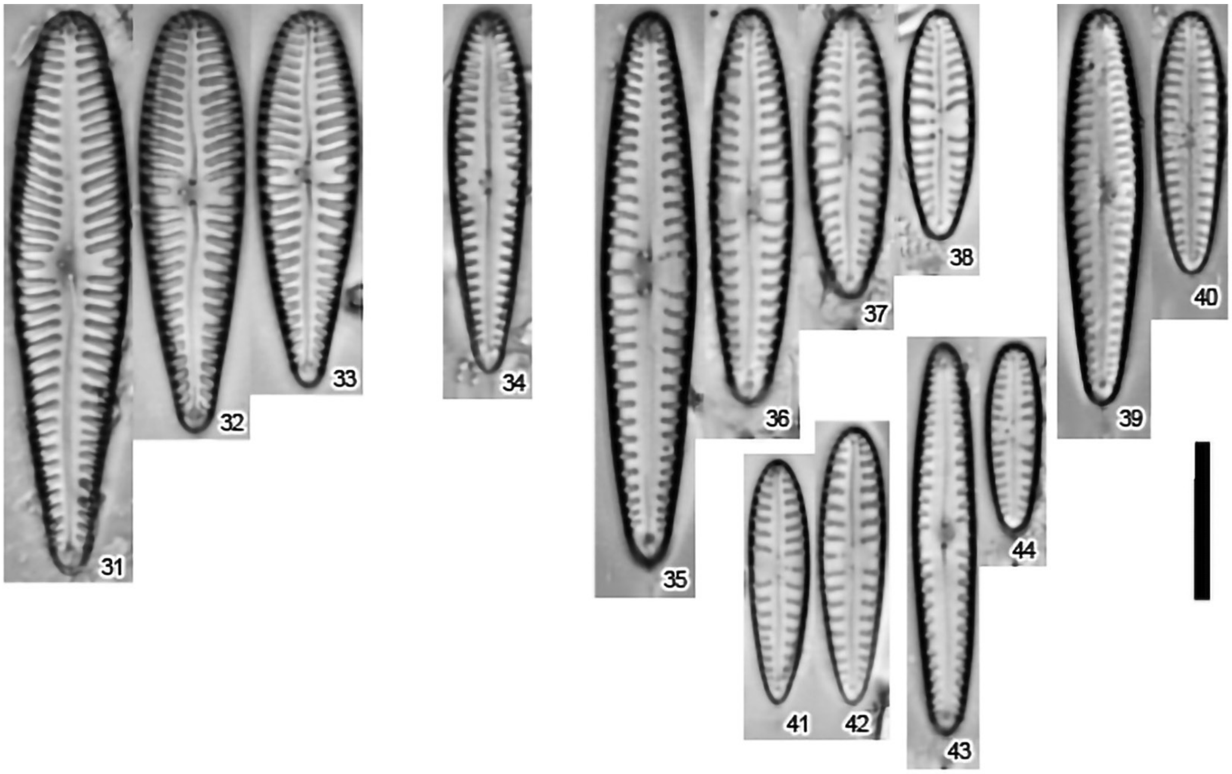
Valves are undulate and elliptical-lanceolate clavate; head pole is broadly capitate and rounded; foot pole is narrowed to capitate ends; axial area is narrow; raphe is markedly undulate; central area has stigma on one side of the central nodule, usually opposite the shortened stria; stria is composed of C-shaped areolae; striae are slightly radiate throughout the valve; foot pole have distinct separate group of small pores called apical pore field that is morphologically different from the areolae; there are 9–10 striae in 10 µm; valve is 30.0–39.3 µm long and 8.6–8.8 µm wide. The dimensions of the specimens observed in Marikina River are within the range as those of the holotype (Ueyama and Kobayasi 1988) and the one observed in China (Liu *et al.* 2021) but smaller in comparison to the dimensions observed in the North American specimens (Polaskey and Vaccarino 2016). **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 29, 37, 42; near agricultural and forested areas). It was observed in these habitats with values ranging from 7.00–7.98, 7.67–8.05, 182.37–381.67, and 120.47–381.67 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

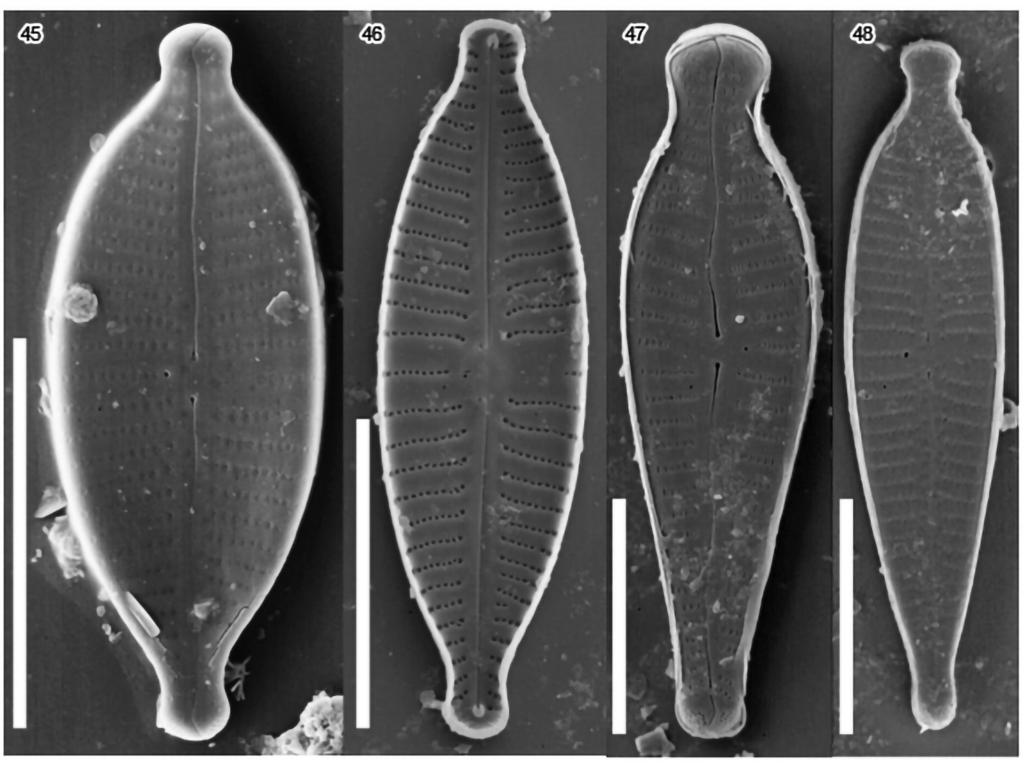
***Gomphonema sphaerophorum* Ehrenberg**
Figures 8–9, 48



Figures 3–30. Light micrographs (LM) of *Gomphonema* species. **Figures 3–5.** *G. lagenula*. **Figures 6–7.** *G. pseudosphaerophorum*. **Figures 8–9.** *G. sphaerophorum*. **Figures 10–12.** *G. chinense*. **Figures 13–15.** *G. javanicum*. **Figure 16.** *G. contraturris*. **Figures 17–19.** *G. exilissimum*. **Figures 20, 22.** *G. parvulum*. **Figures 23–24.** *G. insigniforme*. **Figure 25.** *G. brasiliense* subsp. *pacificum*. **Figures 26-27**. *G. affine.* **Figures 28-30**. *G. bozenae*. Scale bar= 10 µm



Figures 31–44. Light micrographs (LM) of *Gomphonema* species (continued). **Figures 31–33.** *G.* cf. *qingyiensis*. **Figure 34.** *G. sundaense.* **Figures 35–38.** *G. vibrio* var. *bohemicum.* **Figures 39–40.** *G. pumilum*. **Figures 41–42.** *G. cuneolus*. **Figures 43–44.** *G. kobayasii.* Scale bar = 10 µm.



Figures 45–48. Scanning electron micrographs (SEM) of *Gomphonema* species. **Figures 45–46.** *G.lagenula*. **Figure 47.** *G. pseudosphaerophorum*. **Figure 48.** *G. sphaerophorum*. All scale bars = 10 µm.

Ehrenberg (1845), p. 78; Ehrenberg (1854), Plate 35A, Figure VII–14; Patrick and Reimer (1975), p. 133, Plate 17, Figure 5; Podzorski and Håkansson (1987), p. 64; Ueyama and Kobayasi (1988), p. 450, Figure 1–9, 13–24; Polaskey and Bishop (2016); Grover *et al.* (2017), p. 1524, Plate 2, Figure 11.

Valves are clavate; head poles are distinctly capitate; foot poles are narrow; axial area is narrow; central area is transversally elliptic and incomplete; raphe is straight; stigma is present opposite a single shortened stria; striae are parallel at the mid valve, becoming radiate toward the poles; areolae are distinctly punctuated; there are 11–13 striae in 10 µm; valve is 27.9–29.9 µm long and 6.9–7.7 µm wide. Marikina River specimens mostly match Ehrenberg's original description and original drawing (Ehrenberg 1845, 1854), but the valves are shorter than the Japanese specimens (Ueyama and Kobayasi 1988), narrower than North American specimens (Polaskey and Bishop 2016), and have coarser striae than the one observed in Palawan (Podzorski and Håkansson 1987).

Distribution in the Philippines: LUZON: Palawan, Sample 1 (Podzorski and Håkansson 1987).

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 13b, 17, 19, 33, 42; near agricultural, forested, and residential areas). It was observed in these habitats with average values of 7.68, 8.26, 309.61, and 213.36 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema chinense* Liu & Kociolek** Figures 10–12, 49–50

Liu *et al.* (2013), p. 306, Figure 16–31.

Valves are elliptic-lanceolate; head pole is slightly rostrate, foot pole is narrower with rounded end; axial area is broadly lanceolate and narrower toward the apices; central area is slightly wider than the axial area, with one isolated stigma present close to the central nodule; the center of the valve the transverse striae are shorter and more parallel to each other than the striae near the apices; striae density is 10–12 in 10 µm; valves are 23.9–30.9 µm long and 4.2–5.5 µm wide. The specimens observed in Marikina River fit the descriptions of the specimens noted by Liu *et al.* (2013). **A new record for the country.**

Specimen: LUZON: Rizal, Marikina (river, Site Nos. 13b, 41, 42; near forested and agricultural areas). It was observed in these habitats with values ranging from 7.81–8.00, 7.76–8.89, 182.37–349.00, and 120.47–242.00 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema javanicum* Hustedt** Figures 13–15, 51

Hustedt (1938), p. 435, Plate 27, Figures 2–5; Simonsen (1987), p. 237, Plate 344, Figures 19–22; Yana *et al.* (2019), 6–142–6–151.

Valves are small, rhombic-lanceolate, weakly heteropoly, and dorsiventral; apices are rounded, foot pole is capitate, whereas head poles are slightly capitate; axial area is narrow; raphe is straight and slightly curved at the middle; transverse striae are radiate; a stigma is present at the end of a short stria; central area is bow-tie shaped and wider on the opposite side of the stigma; there are 11–13 striae in 10 µm; valves are 17.8–21.9 µm long and 4.4–4.8 µm wide. The specimens observed in Marikina River were within the dimensions as those specimens observed in Java by Hustedt (1938). **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 8, 23, 33, 42; residential and forested areas). It was observed in these habitats with average values of 7.77, 7.87, 234.09, 159.95 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema contraturris* Lange-Bertalot & Reichardt** Figure 16

Lange-Bertalot (1993), p. 57, Plate 78, Figures 2–9, Plate 79, Figures 1–5 (1993); Vouilloud *et al.* (2010), p. 57, Figures 42–45; Medeiros *et al.* (2018), p. 2–3, Figures 2–4.

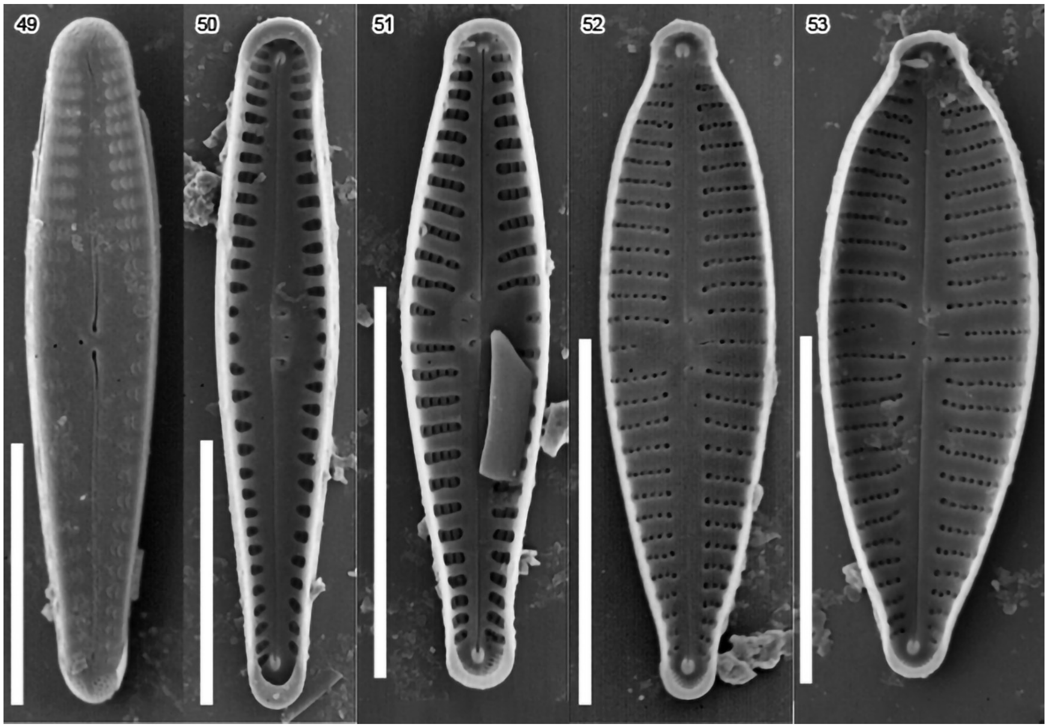
Valves are lanceolate-clavate; margin towards the head pole is angular, not smooth, head pole apiculate, or abruptly end in short truncated ends but getting narrower towards the foot pole ending up to a narrowly rounded end; striae at the center are more distant to each other than those found towards the poles, parallel to slightly radiate all along the valve, except at the poles where they are strongly radiate; the striae at the middle are shorter than the rest but one of them is shorter than the opposite stria; there are 11 striae in 10 µm; valve is 42.7 µm long and 11.0 µm wide. The specimens observed in Marikina River correspond to almost the smallest ones of those originally described by Lange-Bertalot (1993). **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 33, 35, 37, 41, 42, 47, Y2; near agricultural and forested areas). It was observed in these habitats with values ranging from 7.00–7.97, 3.18–8.56, 167.13–294.00, 116.17–202.00 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

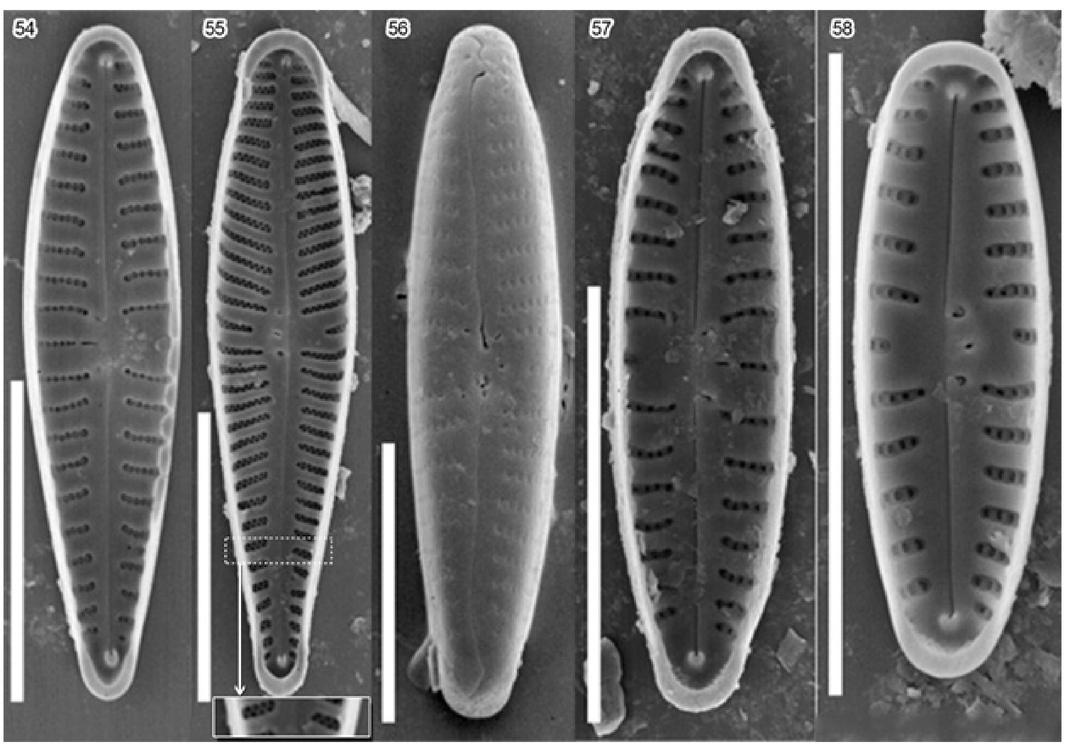
***Gomphonema exilissimum* (Grunow) Lange-Bertalot & E.Reichardt** Figures 17–19, 52

Jüttner *et al.* (2013), p. 305, Figures 1–36; Grover *et al.* (2017), p. 1521, Plate 2, Figure 10; Medeiros *et al.* (2018), p. 11, Figures 31–33, Figures 100–107.

Valves are lanceolate to clavate, apices are sub-capitate to rostrate but not so pronounced, and axial area is narrow



Figures 49–53. Scanning electron microphotographs (SEM) of *Gomphonema* species. **Figures 49–50.** *G. chinense*. **Figure 51.** *G. javanicum*. **Figure 52.** *G. exilissimum*. **Figure 53.** *G. parvulum*. All scale bars = 10 µm.



Figures 54–58. Scanning electron microphotographs (SEM) of *Gomphonema* species. **Figure 54.** *G. bozenae*. **Figure 55.** *G.*cf. *qingyiensis*. **Figures 56–57.** *G. vibrio* var. *bohemicum*. **Figure 58.** *G. kobayasii*. All scale bars = 10 µm.

and linear; central area has shortened striae opposite one another, with one slightly longer stria having an opposite stigma; striae are slightly radiate and more spaced at the central region than near apices; there are 11–15 striae in 10 µm; valve is 15.6–30.0 µm long and 4.6–6.0 µm wide. The dimensions of the specimens from Marikina River are mostly consistent with those of the type specimens studied by Jüttner *et al.* (2013), although Marikina River specimens tend to have coarser striae than the type specimens (11–15 *vs*. 14–16 in 10 µm). The other distinguishing feature of this species is its valve, which is more lanceolate in shape. **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 28, 41; near agricultural and forested areas). It was observed in these habitats with average values of 7.28, 6.82, 152.63, 99.90 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema parvulum* (Kützing) Kützing** Figures 20–22, 53

van Heurck (1896), p. 27, Plate 7, Figure 306; Patrick and Reimer (1975), p. 122, Plate 17, Figure 7–12; Podzorski and Håkansson (1987), p. 63, Plate 22, Figure 6; Wojtal (2003), p. 216, Figure 312–315.

Valves are clavate-lanceolate and narrowing to capitate rostrate ends; forms are variable; axial area is narrow; median striae shorter than the rest, and at its end is an isolated punctum; striae are in the middle of the valve parallel to each other but becoming more radiate toward the poles; there are 10–14 striae in 10 µm, each 17.8–32.8 µm long and 5.7–7.0 µm wide. The morphology of the specimens observed in Marikina River are mostly consistent with the past literature works (van Heurck 1896; Patrick and Reimer 1975; Podzorski and Håkansson 1987; Wojtal 2003). The species is commonly observed in ponds, lakes, and rivers in Luzon and Mindanao (Hustedt 1942) and in Palawan (Podzorski and Håkansson 1987).

Distribution in the Philippines: LUZON: Rizal, Manila, (Bureau of Science, ponds; Hustedt 1942); Laguna, Laguna de Bay (Ohtsuka *et al.* 2009); Laguna, sediment core sample along Laguna de Bay (Antoine *et al.* 1997); Laguna de Bay, Los Baños (ponds) (Hustedt 1942); Camarines Sur, Buhi (Buhi Lake and river); Oriental Mindoro, Naujan (Naujan Lake), Calapan (Caluangan Lake) (Hustedt 1942); Palawan (Podzorski and Håkansson 1987).

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 8, 13, 17, 19, 20, 23, 27, 29, 30, 35, 36, 40, 42, 46, and 47; near agricultural, forested, and residential areas). It was observed in habitats with values ranging from 7.08–8.20, 3.18–9.46, 176.17–455.00, 120.47–315.67 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema insigniforme* Reichardt & Lange-Bertalot** Figures 23–24

Reichardt (1999), p. 10, Plate 3, Figures 1–22; Plate 4, Figures 1–7.

Valves are lanceolate and strongly tapering toward the poles; raphe almost straight; central area is moderately wide and narrows towards the poles; striae radiate, 8–9 striae in 10 µm; valve 25.9–30.3 µm long, 6.4–6.9 µm wide. The dimensions of these specimens (from Marikina River) and the density of the striae were within the range as those previously described by Reichardt (1999). However, there were no observations of any specimens reaching the maximum length of 70 µm. **A new record for the country.**

Specimen: LUZON: Rizal, Marikina (river, Site Nos. 20 and 28, residential and agricultural areas). It was observed in these habitats with average values of 7.15, 6.68, 204.47, and 141.90 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema brasiliense* subsp. *pacificum* G.Moser, Lange-Bertalot & Metzeltin** Figure 25

Moser *et al.* (1998), p. 185, Plate 50, Figures 1–6; Medeiros *et al.* (2018), p. 9, Figures 19–22.

Valves are narrowly lanceolate; head and foot poles are attenuate-rounded; axial area are broad, and central area is indistinct; stigma is absent; striae are short parallel to each other but becoming more radiate toward the poles; there are 12 striae in 10 µm; valves 14 µm long, 3.7 µm wide. The species differs from *G. brasiliense* as described by Patrick and Reimer (1975) by having smaller dimensions and finer striations than the one described by Patrick and Reimer. **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site No. 17, near residential area, rarely observed). It was observed in habitat with a value of 7.84, 9.46, 305.33, 211.00, and 27.50 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema affine* Kützing** Figures 26–27

Patrick and Reimer (1975), p. 133, Plate 17, Figure 5; Ohtsuka *et al.* (2009), p. 140, Figure 5; Medeiros *et al.* (2018), p. 2–3, Figures 2–4.

Valves are lanceolate; head and foot poles are obtuse-rounded; central area has a stigma at the end of a shortened central stria, and the opposite central stria is more shortened; striae are parallel at the median region and becoming more radiate toward the foot pole; there are 6–8 striae in 10 µm; valves are 55.4–69.2 µm long and 10.5–12.1 µm wide. The dimensions of Marikina River specimens are within the range of the dimensions of the *G.*

affine in Brazil (Medeiros *et al.* 2018) and the specimens observed in Laguna de Bay, Philippines (Ohtsuka *et al.* 2009).

Distribution in the Philippines: LUZON: Laguna, Los Banos, Laguna de Bay, (Ohtsuka *et al.* 2009); core samplings around the lake (Antoine *et al.* 1997).

Specimen: LUZON, Rizal, Marikina (river, Site No. 28; agricultural area). It was observed in habitat with a value of 6.75, 5.79, 68.27, and 46.80 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

Gomphonema bozenae **Lange-Bertalot & Reichardt** Figures 28–30, 54

Lange-Bertalot and Metzeltin (1996), p. 68, Plate 65, Figures 11–15, Plate 121, Figures 4–5.

Valves are rhombic-lanceolate-clavate; head poles are gradually taper toward broadly rounded ends; foot poles are narrowed to rounded ends; axial area is narrow; striae are parallel and slightly radiate at the median region; central area has a stigma at the end of a shortened central stria, and the opposite central stria is more shortened; there are 8–9 striae in 10 µm; valves are 25.7–35.7 µm long and 5.4–6.4 µm wide.

The specimens from the Marikina River are almost consistent with the original description by Lange-Bertalot and Metzeltin (1996) in its dimensions but have more strongly heteropolar valve with broader head poles. More typical form of this species has been reported from Laguna de Bay, Philippines (Ohtsuka *et al.* 2009). Marikina River specimens are more similar with *Gomphonema makarovae* Lange-Bertalot in Lange-Bertalot and Genkal (1999) in shape and dimensions, but SEM revealed that the areolae composing striae are much finer in *G. makarovae* (about 9–20 in 10 µm) than in *G. bozenae* (8–10 in 10 µm). Marikina River specimens can also easily be mistaken for *Gomphonema clavatulum* E.Reichardt (Reichardt 1999), but *G. clavatulum* usually has strictly clavate valve, *i.e.* the valve does not gradually taper toward the head pole with denser striae (10.5–14 in 10 µm). The specimen – which has been reported as *G. clavatulum* from Laguna de Bay, Philippines (Ohtsuka *et al.* 2009) – may also be confused as *G. bozenae*, except that *G. clavatulum* (25 µm long and 4.5 µm wide) is smaller than *G. bozenae* from the Marikina River (25.7–35.7 µm long, 5.4–6.4 µm wide), but the shape and the striae density is similar.

Distribution in the Philippines: LUZON: Laguna, Los Banõs, Laguna de Bay (Ohtsuka *et al.* 2009).

Specimen: LUZON, Rizal, Marikina (river, Site No. 13b; near forested area). It was observed in habitat with a value of 8.00, 8.89, 349.00, and 242.00 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

Gomphonema **cf.** ***qingyiensis*** **L-X Zhang, P. Yu & Q-M You** Figures 31–33, 55
Zhang *et al*. (2020), p. 42, Figure 2–43.

Valves are clavate; head pole is rounded, foot pole is strongly narrowed to rounded end; axial area is narrow; central area is wider than the rest of axial area, with stigma (round opening larger than the areolae) at the end of shortened central striae; transverse striae are more radiate at the middle region than at the apices. Striae are biseriate with round, non-occluded areolae (Figures 31–33, 55); there are 9–12 striae in 10 µm; valve is 19.4–35.8 µm long and 6.0–7.7 µm wide. The specimens in Marikina River resemble some *Gomphonema* species with biseriate striae reported from Asia. It is most similar to *Gomphonema qingyiensis* L-X.Zhang, P.Yu & Q-M.You described from Qingyi River, China (Zhang *et al.* 2020, p. 42, Figure 2–43). The dimensions of *G. qingyiensis* (26–41 µm long, 5.6–6.1 µm wide, 8–11 striae in 10 µm) overlap those of Marikina River specimens. However, specimens observed in Marikina River seemed to be broader than *G. qingyiensis* when the lengths are the same; the length/width ratio of the former ranged from 3.4–4.6, whereas that of the latter ranged from 4.6–6.7. Moreover, Marikina River specimens have more radiate striae at the middle than *G. qingyiensis*. Marikina River specimens are also very similar to *Gomphonema doonensis* Karthick, Nautiyal and Kociolek described from Doon Valley, Uttarakhand, India (Karthick *et al.* 2015, p. 168, Figure 17–31). *Gomphonema doonensis*, however, *G. doonensis* has smaller valve (14.0–29.2 µm long and 4.5–5.5 µm wide) than our specimens, although they are similar in shape. *Gomphonema minutum* f. *syriacum* Lange-Bertalot & E.Reichardt described from Orontes River, Syria (Lange-Bertalot 1993, p. 64; Krammer and Lange-Bertalot 1986, Plate 81, Figure 9–14) is similar to our specimens in terms of dimensions (16–40 µm long, 5.3–7.5 µm wide, about 10 striae in 10 µm), although it has not been known whether it has biseriate striae. However, this specimen was not identified as *G. minutum* f. *syriacum* because the valve outlines are different to each other. Marikina River specimens have clavate valve with broadly rounded head pole, whereas *G. minutum* f. *syriacum* usually has more lanceolate valve with narrower head pole. **A new record for the country.**

Specimen: LUZON: Rizal, Marikina (river, site no. Y1; near agricultural area). It was observed in habitat with a value of 7.48, 91.60, and 62.83 for DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

Gomphonema sundaense **E.Reichardt** Figure 34

Simonsen (1987), Plate 237, Plate 345, Figures 1–5 (as *G. clevei* var. *javanicum*); Reichardt (2005), p. 129–131, Plate 6, Figures 1–8.

Valves are small and elliptical-lanceolate-clavate with both poles narrowing to rounded apices, although the head pole is usually broader than the foot pole; axial area is wide; raphe is straight but weakly curved at the middle region; central area is indistinct, median striae are slightly shortened on both sides, and stigma is found at the end of one of the striae; transverse striae are slightly radiate, there are 12 striae in 10 µm; valve is 23.1 µm long and 5.0 µm wide. **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site No. 42; near forested area; rare). It was observed in habitat with a value of 7.97, 7.76, 182.37, and 120.47 for pH, DO (mg · L^{-1}), conductivity (µ · s^{-1}), and TDS (ppm), respectively.

***Gomphonema vibrio* var. *bohemicum* (Reichelt & Fricke) R. Ross** Figures 35–38, 56, 57

Fricke (1902), Plate 235, Figures 18–25; Reichardt (1999), p. 53, Plate 51, Figures 1–22, Plate 51, Figures 1–5.

Valves are linear-lanceolate and gradually narrowing into rounded apices; axial area is moderately wide; raphe is straight but ends are slightly curved; central area is rectangular, median striae are shortened; transverse striae are radiate; striae density is 8–12 in 10 µm; valves are 14.7–36.5 µm long and 4.5–6.8 µm wide. The dimensions of Marikina River specimens mostly match the description by Reichardt (1999), but smaller specimens were also observed. **A new record for the country**.

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 13, 16, 21, 23, 33, 36, 42, 46; near agricultural, residential, and forested areas; frequently observed). It was observed in these habitats with values ranging from 7.05–8.20, 4.41–8.83, 182.37–432.33, and 120.47–301.67 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema pumilum* (Grunow) Reichardt & Lange-Bertalot** Figures 39–40

Reichardt (1997), p. 528, Plate 6: Figures 4–11; Wojtal (2003), p. 217, Fig. 4: 1–6; Medeiros *et al.* (2018), p. 19, Figures 4–11, Figures 67–69; Solak *et al.* (2021), p. 212.

Valves are lanceolate; head pole is rounded; foot pole is narrowly rounded; axial area is narrow; central area is small; stigma is present at the end of median stria; transverse short striae are parallel to each other at the median region but becoming more radiate toward the apices; there are 11–12 striae in 10 µm; valves are 16.2–25.2 µm long and 4.3–5.2 µm wide. The length of this (Marikina) specimen was much smaller than those observed by Wojtal (2003), Medeiros *et al.* (2018), and Solak *et al.* (2021).

Distribution in the Philippines: MINDANAO: Lanao del Sur, Madamba (Uyaan Lake), (Hustedt 1942); reported as *G. intricatum* var. *pumila* (*pumilum*) Grunow (basionym).

Specimen: LUZON, Rizal, Marikina (river, Site No. 10; near forested area). It was observed in habitat with a value of 7.68, 7.20, 252.00, and 174.00 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema cuneolus* E.Reichardt** Figures 41–42

Reichardt (1997), p. 123, Plate 11, Figures 1–18.

Valves are elliptic-lanceolate, head pole is roundly cuneate, foot pole is gradually narrowing into cuneate apices; axial area is narrow; raphe is straight but ends slightly curved; transverse striae are radiate; central area expanded on the opposite side of the stigma; there are 10–12 striae in 10 µm; valves are 15.5–17.8 µm long and 4.2–4.4 µm wide. The specimens observed in Marikina River fit the descriptions of the specimens described by Reichardt (1997). **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site No. 28; near agricultural area). It was observed in habitat with a value of 6.75, 5.79, 68.27, and 46.80 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

***Gomphonema kobayasii* Kociolek & Kingston** Figures 43–44, 58

Kociolek and Kingston (1999), p. 701, Figures 83–90, 96–102; Kociolek (2011).

Valves are linear-clavate; head pole is rounded; foot pole is narrowly rounded; axial area is narrow; striae are short parallel to each other at the central area but becoming more radiate toward the apices, especially toward the foot pole; central area is broadly rectangular, stigma is present; there are 10–14 striae in 10 µm; valves are 9.9–25.0 µm long and 3.2–4.3 µm wide. The specimens observed in Marikina River have similar dimensions as those observed by Kociolek and Kingston (1999) and Kociolek (2011) but have somewhat narrower valve with denser striae. **A new record for the country.**

Specimen: LUZON, Rizal, Marikina (river, Site Nos. 17, 28, 42; forested, residential, and agricultural areas). It was observed in these habitats with average values of 7.52, 7.67, 185.32, and 126.09 for pH, DO (mg · L^{-1}), conductivity (µS·cm^{-1}), and TDS (ppm), respectively.

Habitat Characteristics

Table 2 shows the mean values for the 11 physico-chemical parameters taken in the study sites. The data show that the study sites are wadable, slow-flowing, freshwater tropical streams, generally with basic pH waters. The water quality data of the sites had narrow ranges for pH and water temperature but wider ranges for conductivity and TDS readings. Table 3 shows the frequency of occurrence of the different *Gomphonema* species in the 30 collecting sites of Marikina River watershed. Of the 18 species observed in the study site, *G. parvulum* was noted to be the most frequently observed species. It was observed in about 50% of the collecting sites. The other species that were frequently observed were the following in decreasing order: *G. lagenula*, *G. vibrio* var. *bohemicum*, *G.contraturris*, *G. sphaerophorum*, and *G. javanicum.*

Among the least occurring species, in decreasing order, were: *G. chinense*, in equal frequency with *G. kobayasii* and *G. pseudosphaerophorum*; *G. exilissimum,* in equal frequency with *G. insigniforme*; the rest of these species

Table 2. Mean abiotic parameters in the collecting sites in Marikina River, Rizal, Philippines in October–November 2016.

No.	Site identification	[1]DO (mg · L^{-1})	pH	Conductivity (µS · cm^{-1})	[2]TDS ppm	Water temperature (°C)	Salinity ppm	Flow velocity (cm · s^{-1})	Water depth (cm)	Elevation ([3]masl)	Stream width (m)	Canopy cover (%)
1	8	7.42	7.88	274.00	189.33	24.17	124.33	60.42	17.50	130.00	11.50	56.00
2	10	7.20	7.68	252.00	174.00	27.03	115.00	64.28	19.00	110.00	9.80	50.97
3	13	8.83	8.15	282.33	198.00	24.50	132.00	41.64	24.33	58.00	12.70	26.73
4	13b	8.41	8.00	349.00	242.00	26.63	163.33	81.78	19.77	93.00	6.10	69.37
5	**15	5.22	7.61	235.00	164.00	26.37	108.67	49.30	13.47	57.00	ND	35.80
6	16	9.46	7.79	352.33	218.00	27.30	152.33	44.97	17.50	34.00	7.57	51.37
7	17	7.09	7.84	305.33	211.00	27.50	140.00	47.17	20.33	172.00	5.13	83.67
8	19	7.57	7.54	455.00	315.67	27.57	210.33	19.37	21.33	144.00	6.87	84.07
9	20	4.41	7.55	340.67	237.00	26.00	158.33	24.52	17.67	163.00	ND	75.13
10	21	8.19	7.53	432.33	301.67	28.47	199.00	45.50	30.00	154.00	12.72	57.63
11	23	6.88	8.20	223.67	152.33	25.73	102.33	49.10	11.67	55.00	11.25	45.37
12	26	5.71	7.48	216.67	150.00	29.53	97.67	43.91	20.67	29.00	18.50	59.77
13	27	5.79	7.24	217.33	152.00	26.60	87.93	105.04	9.17	38.00	10.90	47.90
14	28	8.05	6.75	68.27	46.80	27.50	40.46	32.51	10.50	209.00	49.00	29.40
15	29	8.46	7.98	381.67	263.67	25.70	174.00	55.66	12.67	212.00	6.16	83.53
16	30	7.76	8.09	381.33	265.33	25.37	177.33	59.53	12.83	222.00	5.00	61.23
17	**31	5.35	7.53	203.00	141.33	24.73	94.33	52.31	13.17	182.00	4.8	30.30
18	32	8.10	6.61	324.33	224.00	27.17	144.33	32.13	12.33	167.00	7.60	21.53
19	33	8.56	7.05	256.33	177.67	24.50	119.00	64.78	13.83	235.00	ND	65.13
20	35	8.33	7.48	220.00	150.67	25.62	102.33	87.26	26.17	144.00	14.00	31.10
21	36	7.81	7.29	235.33	165.00	23.57	115.33	71.68	19.33	170.00	14.00	55.00
22	37	7.69	7.00	266.00	184.33	24.00	122.00	39.82	15.83	174.00	6.20	76.83
23	40	7.84	7.80	176.17	121.53	29.37	92.43	90.44	33.44	68.00	10.00	56.63
24	41	7.76	7.81	237.00	153.00	29.63	101.83	45.07	43.60	73.00	ND	25.53
25	42	5.84	7.97	182.37	120.47	26.23	70.97	73.58	66.78	76.00	ND	72.70
26	**45	7.67	7.87	485.67	336.33	24.43	220.33	33.59	7.00	42.00	17.1	18.77
27	46	3.18	7.81	362.67	247.33	28.27	172.00	52.72	9.50	46.00	ND	61.30
28	47	8.89	7.08	294.00	202.00	28.73	134.00	76.93	9.83	45.00	9.40	35.30
29	Y1	7.48	*ND	91.60	62.83	24.00	41.63	43.94	15.67	415.00	6.10	73.33
30	Y2	6.94	ND	167.13	116.17	25.77	80.23	45.50	9.00	393.00	3.50	85.53
Ranges		3.18–9.46	6.61–8.20	68.27–455.00	46.80–315.67	23.57–29.63	40.46–210.33	19.37–105.04	9.00–66.78	29.00–415.00	3.50–49.00	21.53–85.53
Mean		7.26	7.59	275.62	189.45	26.40	126.46	54.48	19.13	137.00	11.08	54.23

[ND] no data; [**] collecting sites wherein no *Gomphonema* species were observed; [1][DO] dissolved oxygen; [2][TDS] total dissolved solids; [3][masl] meters above sea level

Table 3. List of *Gomphonema* species observed in Marikina River, Rizal, Philippines, their frequency of occurrence in the different sites, type of stream reach, and land use from October–November 2016.

***Gomphonema* species**	**Frequency of occurrence**	**Type of stream reach**		**Land use***
		Sensu stricto	More general	
lagenula	8		Upstream, midstream, downstream	A, F, R
pseudosphaerophorum	3	Downstream	Midstream, downstream	A, F
sphaerophorum	5		Upstream, downstream	A, F, R
chinense	3		Upstream, midstream	A, F
javanicum	4	Upstream	Upstream, downstream	F, R
contraturris	7	Midstream	Midstream	A, F
exilissimum	2		Midstream, downstream	A, F
parvulum	15	Upstream, midstream, downstream	Upstream, midstream, downstream	A, F, R
insigniforme	2		Midstream	A, R
brasiliense subsp. *pacificum*	1		Downstream	R
affine	1		Downstream	A
bozenae	1		Upstream	F
cf. *qingyiensis*	1		Midstream	A
sundaense	1		Midstream	F
vibrio var. *bohemicum*	8		Upstream, midstream, downstream	A, R, F
pumilum	1	Upstream	Upstream	F
cuneolus	1		Downstream	A
kobayasii	3		Midstream, downstream	A, F, R

*Land use: [A] agricultural; [F] forested; [R] residential

were only noted in one site: *G. affine*, *G. bozenae*, *G. brasiliense* subsp. *pacificum*, *G. cuneolus*, *G. pumilum*, *G.* cf. *qingyiensis*, and G. *sundaense.* Table 4 shows that among the species, *G. parvulum* had a wide range of tolerance to DO (ranging from 3.18–9.46 mg · L^{-1}) and to TDS (120.47–315.67 ppm). It was also found in all three types of stream reach and all types of land use (Table 3). *G. sphaerophorum* was noted in sites with TDS that ranged from 129.47–315.6 ppm (Table 4), whereas *G. exilissimum* was noted in sites with TDS that ranged from 46.8–153 ppm. All 18 species were found in all 30 collecting sites except in three sites (15, 31, and 45). These three sites were found along residential places with % canopy cover that ranged from 18.7–35.8% (Table 2). On the other hand, the percentage canopy cover of the sites with observed *Gomphonema* species ranged from 21.5–85.3% (Table 2). However, overall, it was found that the two groups of collecting sites, *i.e.* those with observed *Gomphonema* species (n = 27) and those without the said species (n = 3) were significantly different in terms of canopy cover (%). Using Student's t-test, it showed that the mean difference of 28.8 between the canopy cover (%) of the collecting sites in Marikina River, where the *Gomphonema* species were observed and not observed was significant (*p*-value = 0.018) (Tables 4 and 5). Collecting sites with observed *Gomphonema* species had higher mean canopy cover percentage of 57.11% than the sites without the observed species with only 28.29%. The differences among the other characteristic features were not found to be statistically significant.

DISCUSSION

Among the 18 *Gomphonema* species observed in Marikina River, *G. parvulum* seems to be most widely occurring. This was also noted in previous studies (Krammer and Lange-Bertalot 1986), especially in eutrophic/polluted waters (Wan Maznah and Mansor 2002; Venkatachalapathy and Karthikeyan 2013; Lu *et al.* 2020; Yu *et al.* 2021). In this study the only indications that *G. parvulum* was found in eutrophic waters/polluted waters were its presence in the downstream area, near residential

Table 4. A comparison of the mean and tolerance values (range values) in the different abiotic factors, of the different *Gomphonema* species in the 30 collecting sites in Marikina River, Rizal, Philippines from October–November 2016.

***Gomphonema* species**	**Dissolved oxygen ($mg \cdot L^{-1}$)**		**pH**		**Conductivity ($\mu S \cdot cm^{-1}$)**		**TDS (ppm)**		**Flow velocity ($cm \cdot s^{-1}$)**		**Canopy cover (%)**	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
lagenula	5.35–8.89	7.51	6.61–8.20	7.53	68.27–349.00	253.12	46.80–242.00	175.10	24.52–87.26	49.11	21.53–75.13	44.80
pseudosphaerophorum	7.76–8.05	7.87	7.00–7.98	7.65	182.37–381.67	276.68	120.47–381.67	189.49	39.82–73.58	56.35	72.70–83.53	77.69
sphaerophorum	7.09–9.46	8.26	7.05–8.00	7.68	182.37–455.00	309.61	120.47–315.67	213.36	19.37–81.78	57.33	65.13–84.07	74.99
chinense	7.76–8.89	8.16	7.81–8.00	7.93	182.37–349.00	256.12	120.47–242.00	171.82	45.07–81.78	66.81	25.53–72.70	55.87
javanicum	7.42–8.19	7.87	7.05–8.20	7.77	182.37–274.00	234.09	120.47–189.33	159.95	49.10–73.58	61.97	45.37–72.70	59.80
contraturris	3.18–8.56	7.17	7.00–7.97	7.40	167.13–294.00	231.83	116.17–202.00	157.76	39.82–87.26	61.85	25.53–85.53	56.02
exilissimum	5.79–7.84	6.82	6.75–7.81	7.28	68.27–237.00	152.63	46.80–153.00	99.90	32.51–45.07	38.79	25.53–29.40	27.47
parvulum	3.18–9.46	7.60	7.08–8.20	7.73	176.17–455.00	288.79	120.47–315.67	199.42	19.37–105.04	61.00	26.73–84.07	58.38
insigniforme	5.79–7.57	6.68	6.75–7.55	7.15	68.27–340.67	204.47	46.80–237.00	141.90	24.52–32.51	28.52	29.40–75.13	52.27
brasiliense subsp. *pacificum*	9.46	9.46	7.84	7.84	305.33	305.33	211.00	211.00	47.17	47.17	83.67	83.67
affine	5.79	5.79	6.75	6.75	68.27	68.27	46.80	46.80	32.51	32.51	29.40	29.40
bozenae	8.89	8.89	8.00	8.00	349.00	349.00	242.00	242.00	81.78	81.78	69.37	69.37
cf. *qingyiensis*	7.48	7.48	*ND	ND	91.60	91.60	62.83	62.83	43.94	43.94	73.33	73.33
sundaense	7.76	7.76	7.97	7.97	182.37	182.37	120.47	120.47	73.58	73.58	72.70	72.70
vibrio var. *bohemicum*	4.41–8.83	7.32	7.05–8.20	7.72	182.37–432.33	290.92	120.47–301.67	197.56	41.64–73.58	55.50	26.73–72.70	54.40
pumilum	7.20	7.20	7.68	7.68	252.00	252.00	174.00	174.00	64.28	64.28	50.97	50.97
cuneolus	5.79	5.79	6.75	6.75	68.27	68.27	46.80	46.80	32.51	32.51	29.40	29.40
kobayasii	5.79–9.46	7.67	6.75–7.97	7.52	68.27–305.33	185.32	46.80–211.00	126.09	32.51–73.58	51.09	29.40–83.67	61.92

*[ND] no data

places, and in waters with DO as low as 3.18 $mg \cdot L^{-1}$, TDS as high as 315.67 ppm, and electrical conductivity reading (EC) as high as 455 $\mu S \cdot cm^{-1}$. However, the values for TDS and EC in this study were much lower than what was observed in a river in South India that was influenced by urban pollution, where *G. parvulum* was one of the predominant species, *i.e.* 560–937 ppm (TDS), 1,015.6–1,223 $\mu S \cdot cm^{-1}$ (EC) (Venkatachalapathy and Karthikeyan 2013). *G. sphaerophorum* may indicate eutrophic conditions, too, because it was observed in the downstream zone, along residential places, and in sites with high values for conductivity readings and TDS. This species was also considered as a mixed pollution tolerant species together with *G. parvulum* in Ganga River, mostly filled with discharges from city sewage, in Allahabad, India (Dwivedi and Srivastava 2017). Whereas the presence of *G. exilissimum* may indicate oligotrophic waters, particularly in site 41, in a forested area, at midstream region with DO value of 7.84 $mg \cdot L^{-1}$, EC reading of 237 $\mu S \cdot cm^{-1}$, and TDS of 153 ppm. This species was also considered an oligotrophic type in assessing the tropic status of lakes in the lower reaches of Yangtze River in China because it had lower tolerances for total nitrogen, total phosphorus, and COD (Yu *et al.* 2021). Hence, despite the world-wide distribution of the species of *Gomphonema* their species exhibit differences in ecological characteristics. On the other hand, the great variation in habitat characteristics in Marikina River may have enhanced the great diversity of *Gomphonema* species in this study.

Table 5. Independent sample t-test for comparing the feature characteristic means between the two groups of collecting sites (those with *Gomphonema* species and those without *Gomphonema* species).

Feature	Test	*p*	Mean difference
Dissolved oxygen (mg · L^{-1})	Mann-Whitney U	0.514	1.94e–6
pH	Mann-Whitney U	0.756	–0.0600
Conductivity (µS · cm^{-1})	Student's t	0.559	–35.9
Total dissolved solids (ppm)	Student's t	0.522	–27.2
Temperature (°C)	Student's t	0.209	1.36
Salinity (ppm)	Student's t	0.560	–16.3
Flow velocity (cm · s^{-1})	Student's t	0.402	10.5
Depth (cm)	Mann-Whitney U	0.128	5.83
Elevation (masl)	Mann-Whitney U	0.489	30.0
Stream width (m)	Mann-Whitney U	0.958	0.246
Canopy cover (%)	Student's t	0.018	28.8

Geographically, *Gomphonema* diversity of the Marikina River appears to be composed of cosmopolitan, Circum-Pacific, pan-tropical, and Asian endemic species. For instance, *G. parvulum* is a typical cosmopolitan species (Krammer and Lange-Bertalot 1986). *Gomphonema pseudosphaerophorum* is probably a Circum-Pacific species because it has been reported from only Asia and North America (Polaskey and Vaccarino 2016). *Gomphonema contraturris* is considered to be pan-tropical species, although it sometimes occurs in temperate regions (Lange-Bertalot 1993). Reliable reports of *G. javanicum* are limited to Southeast Asia (Hustedt 1938; Yana *et al.* 2019). *Gomphonema* cf. *qingyiensis* is probably a member of a species flock of tropical *Gomphonema* species with biseriate striae, but it appears to belong to different species from both Chinese *G. qingyiensis* (Zhang *et al.* 2020) and Indian *G. doonensis* (Karthick *et al.* 2015).

CONCLUSION

In this study a detailed taxonomic description of *Gomphonema* species was done to understand the benthic diatom flora and their diversity in Marikina River. These specimens were collected from upper to downstream of the river, covering diverse land use within the watershed. Species diversity of diatoms is an important aspect of the aquatic ecosystem, but it is still little-known in Philippine inland waters. In the Marikina River, we conducted the first comprehensive study of *Gomphonema* Agardh. A total of 18 taxa were identified in the Marikina River, giving a total of 44 taxa known in the Philippines, including the previous studies up to this date. There were 12 *Gomphonema* species observed to be new records for the Philippines in this study. Habitat description for each species is given. In terms of their geographic distribution, most of the species are cosmopolitan. This study is the first step to establish water quality indices using diatoms in Philippine rivers.

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REFERENCES

AL FALAH MH, SOEPROBOWATI TR, HADIYANTO. 2023. Epipelic diatom assemblages to determine water quality in the Tuntang River downstream, Demak, Central Java. IOP Conference Series: Earth and Environmental Science 1137 (1): 1–12. DOI: 10.1088/1755–1315/1137/1/012003

ANTOINE R, BENSON-EVANS K, MARTINEZ MR. 1997. Paleolimnological studies of Laguna de Bay, Philippines: evidence from Diatoms. Limnologica 27(2): 165–167.

BELTON TJ, PONADER KC, CHARLES DF. 2005. Trophic diatom indices (TDI) and the development of site-specific nutrient criteria. Proceedings of the Water Environment Federation (3): 1042–1056. DOI: 10.2175/ 193864705783966800

CANENCIA OP, GOMEZ AL. 2016. Water quality standards and plankton species composition in selected river system in Cagayan de Oro City, Philippines. Journal of Biodiversity and Environmental Sciences 9(5): 110–116.

DESCY JP. 1979. A new approach to water quality estimation using diatoms. Nova Hedwigia Beiheft 64: 305–323.

DIMERO DN, CRUZATE SM, BONO MT, CREUS JK. 2021. Diversity of diatoms in selected rivers of Indang, Cavite, Philippines and their correlation to water properties. The Thailand Natural History Museum Journal 14(2): 39–50.

DWIVEDI B, SRIVASTAVA AK. 2017. Diatoms as indicator of pollution gradients of the River Ganga, Allahabad, India. International Journal of Current Microbiology and Applied Science 6(7): 4323–4334.

EHRENBERG CG. 1845. Neue Untersuchungen über das kleinste Leben als geologisches Moment Ber Bekanntm Verh Königl Preuss Akad Wiss Berlin: 53–87. Leopold Voss.

EHRENBERG CG. 1854. Mikrogeologie: Leipzig: Leopold Voss, Plate 35A, Figures 7–14.

FRICKE F. 1902. Tafel 235. In: Dr. A. Schmidt's Atlas der Diatomaceen-Kunde. p. 234–235, Figures 18–25.

GALINATO M, EVANGELIO J. 2016. Dynamics of Plankton Community in Banahao-Palhi River in Leyte, Philippines. Annals of Tropical Research 38(2): 130–152. DOI: 10.32945/atr3829.2016

GROVER S, SRIVASTAVA P, VERMA J, KHAN AS. 2017. Eco-taxonomical studies on diatoms from the Chambal River (Central India). Plant Archives 17(2): 1517–1532.

GUIRY MD, GUIRY GM. 2023. AlgaeBase. Accessible at https://algaebase.org

HEINRICH CG, PALACIOS-PEÑARANDA ML, PEÑA-SALAMANCA E, SCHUCH M, LOBO EA. 2019. Epilithic diatom flora in Cali River hydrographical basin, Colombia. Rodriguésia 70: 1–28. DOI: 10.1590/2175–7860201970041

HUSTEDT F. 1938. Systematische und okologische Untersuchungen ber die Diatomeen-Flora von Java, Bale und Sumatra nach dem Material der Deutchen limnologischen Sunda-Expedition. Arch. Hydrobiol 15: 638–790.

HUSTEDT F. 1942. Süßwasser-Diatomeen des indomalayischen Archipels und der Hawaii-Inseln. Nach dem Material der Wallacea-Expedition. Internationale Revue Der Gesamten Hydrobiologie Und Hydrographie 42(1–3): 1–252. DOI: 10.1002/ iroh.19420420102

JOHNSON K. 2018. *Gomphonema lagenula*. Diatoms of North America. Accessible at https://diatoms.org/species/gomphonema-lagenula

JÜTTNER I, ECTOR L, REICHARDT E, VAN DE VIJVER B, JARLMAN A, KROKOWSKI J, COX EJ. 2013. *Gomphonema varioreduncum* sp. nov., a new species from northern and western Europe and a re-examination of *Gomphonema exilissimum*. Diatom Research 28(3): 303–316. DOI: 10.1080/0269249X.2013.797924

KARTHICK B, NAUTIYAL R, KOCIOLEK JP, RAMACHANDRA T. 2015. Two new species of *Gomphonema* (Bacillariophyceae) from Doon Valley, Uttarakhand, India. Nova Hedwiga 144: 165–174. DOI: 10.1127/nova_suppl/2015/0037

KAWANOBE K, IKEYA T. 2016. An examination of fixatives and sample storage temperature for marine phytoplankton preservation; comprehensive policies on quality and risk control. Bulletin of Phytoplankton Society of Japan 63(2): 55–65.

KELLY MG, WHITTON BA. 1995. The Trophic Diatom Index: a new index for monitoring eutrophication in rivers. Journal of Applied Phycology 7(4): 433–444. DOI: 10.1007 /BF00003802/METRICS

KERMARREC L, ECTOR L, BOUCHEZ A, FRÉDÉRIC RIMET F, HOFFMANN L. 2011. A preliminary phylogenetic analysis of the Cymbellales based on 18S rDNA gene sequencing. Diatom Research 26(3): 305–315. https://doi.org/10.1080/0269249X.2011.633255

KHAN ISAN I. 2015. Periphytic diatoms in the polluted Linggi (*sensu stricto*) and Kundor Rivers, Negeri Sembilan, Malaysia. ASEAN Journal on Science and Technology for Development 32(1): 60–84. DOI: 10.29037/ajstd.12

KOCIOLEK JP, KINGSTON JC. 1999. Taxonomy, ultrastructure, and distribution of some gomphonemoid diatoms (Bacillariophyceae: Gomophonemataceae) from rivers in the United States. Canadian Journal of Botany 77(5): 686–705. DOI: 10.1139/cjb–77–5–686

KOCIOLEK P. 2011. *Gomphonema kobayasii*. Diatoms of North America. Accessible at https://diatoms.org/species/gomphonema_kobayasii

KOCIOLEK JP, BLANCO S, COSTE M, ECTOR L, LIU Y, KARTHICK B, KULIKOVSKIY M, LUNDHOLM N, LUDWIG T, POTAPOVA M, RIMET F, SABBE K, SALA S, SAR E, TAYLOR J, VAN DE VIJVER B, WETZEL CE, WILLIAMS DM, WITKOWSKI A, WITKOWSKI J. 2023. DiatomBase. Accessed on 22 Jun 2023 at https://www.diatombase.org; DOI: 10.14284/504

KRAMMER K, LANGE-BERTALOT H. 1986. Bacillariophyceae 1. Teil: Naviculaceae; 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae; 3. Teil: Centrales, Fragilariaceae, Eunotiaceae; 4. Teil: Achnanthaceae. Kritische Ergänzungen Zu *Navicula* (Lineolatae) Und *Gomphonema* 2: 876p.

LANGE-BERTALOT H. 1993. 85 Neue Taxa und über 100 weitere neu definierte Taxa ergänzend zur Süßwasserflora von Mitteleuropa Vol. 2/1–4. Schweizerbart Science Publishers.

LANGE-BERTALOT H, GENKAL SI. 1999. Diatoms from Siberia: islands in the Arctic Ocean (Yugorsky Shar Strait). In: Iconographia Diatomologica. Gantner.

LANGE-BERTALOT H, METZELTIN D. 1996. Indicators of oligotrophy. 800 taxa representative of three ecologically distinct lake types, carbonate buffered-Oligodystrophic-weakly buffered soft water. Lange-Bertalot H ed. Koeltz Scientific Books.

LIU Q, CUI N, FENG J, LÜ J, NAN F, LIU X, XIE S, KOCIOLEK JP. 2021. *Gomphonema* Ehrenberg species from the Yuntai Mountains, Henan Province, China. Journal of Oceanology and Limnology 39(3): 1042–1062. DOI: 10.1007 /s00343–020–0103–9

LIU Y, KOCIOLEK JP, WANG Q. 2013. Six new species of *Gomphonema* Ehrenberg (Bacillariophyceae) species from the Great Xing'an Mountains, Northeastern China. Cryptogamie, Algologie 34(4): 301. DOI: 10.7872/crya.v34.iss4.2013.301

LU X, LIU Y, FAN Y. 2020. Diatom taxonomic composition as a biological indicator of the ecological health and status of a River Basin under agricultural influence. Water (Switzerland) 12(7). DOI: 10.3390/w12072067

MALARAN FF, SUMAGAYSAY KA, NACASABOG JJS, CANENCIA MOP. 2019. Species composition and diversity of periphytic diatoms along Umalag River, Philippines. Journal of Biodiversity and Environmental Sciences 14(1): 121–130.

MANN A. 1925. Marine Diatoms of the Philippines. Smithsonian Institution United States National Museum. In: Bulletin 100. Government Printing Press. 182p.

MARTINEZ-GOSS MR, EVANGELISTA LT, NACORDA JO, MANDIA EH, TORRETA NK. 2020. Preparation of diatoms for light and electron microscopy. In: Methods in Microalgal Studies . Martinez-Goss *et al.* ed. PSL and UPLB. p. 75–86.

MEDEIROS G, AMARAL MWW, FERREIRA PC, LUDWIG TV, BUENO NC. 2018. *Gomphonema* Ehrenberg (Bacillariophyceae, Gomphonemataceae) of the São Francisco Falso River, Paraná, Brazil. Biota Neotropica 18(3): 23p. DOI: 10.1590 /1676–0611–bn–2017–0495

MOSER G, LANGE-BERTALOT H, METZELTIN D. 1998. Insel der Endemiten. Geobotanisches Phänomen Neukaledonien = Island of Endemics. New Caledonia - a botanical phenomenon. Schweizerbart Science Publishers.

OHTSUKA T, KATO S, ASAI K, WATANABE T. 2009. Checklist and illustrations of diatoms in Laguna de Bay, Philippines, with reference to water quality. Diatom 25: 134–147.

OMAR WMW. 2010. Perspectives on the use of algae as biological indicators for monitoring and protecting aquatic environments, with special reference to Malaysian freshwater ecosystems. Tropical Life Sciences Research 21(2): 63–79.

PATRICK R, REIMER CW. 1975. The Diatoms of the United States (Exclusive of Alaska and Hawaii) (Issue v. 2, pt. 1). Academy of Natural Sciences, Philadelphia, Pennsylvania, United States.

PERALTA EM, BELEN AE, BUENAVENTURA GR, CANTRE FGG, ESPIRITU KGR, DE VERA JNA, PEREZ CP, TAN AKV, DE JESUS IBB, PALOMARES P, BRIONES JCA, IKEYA T, MAGBANUA FS, PAPA RDS, OKUDA N. 2019. Stream Benthic Macroinvertebrate Assemblages Reveal the Importance of a Recently Established Freshwater Protected Area in a Tropical Watershed. Pacific Science 73(3): 305–320. DOI: 10.2984/73.3.1

[PSA] Philippine Statistics Authority. 2021. 2021 Philippine Statistical Yearbook. Quezon City, Philippines. p. 1.

PODZORSKI AC, HÅKANSSON H. 1987. Freshwater and Marine Diatoms from Palawan (a Philippine Island). Biblioth Diatomol 13: 1–245.

POLASKEY M, BISHOP I. 2016. *Gomphonema sphaerophorum*. Diatoms of North America. Retrieved from https://diatoms.org/species/gomphonema_augur_var._sphaerophorum

POLASKEY M, VACCARINO M. 2016. *Gomphonema pseudosphaerophorum*. Diatoms of North America. Retrieved from https://diatoms.org/species/gomphonema_ pseudo sphaerophorum.

REICHARDT E. 1997. Taxonomic revision of *Gomphonema pumilum* (Bacillariophyceae) species. Nova Hedwigia 65(1–4): 99–129. DOI: 10.1127/ nova. hedwigia/65/ 1997/99

REICHARDT E. 1999. Zur Revision der Gattung *Gomphonema*: Die Arten um *G. affine/insigne, G. angustatum/micropus, G. acuminatum* sowie gomphonemoide Diatomeen aus dem Oberoligozän in Böhmen. Koeltz Scientific Books.

REICHARDT E. 2005. Die Identitat von *Gomphonema* entolejum Ostrup (Bacillariophyceae) sowie Revision ahnlicher Arten mit weiter Axialarea. Nova Hedwigia 81(1–2): 115–144. DOI: 10.1127/0029–5035/2005/0081–0115

[RBCO-DENR] River Basin Control Office–Department of Environment and Natural Resources 2015. Formulation of an Integrated River Basin Management and Development Master Plan for Marikina River Basin. Quezon City, Philippines.

ROUND FE, CRAWFORD RM, MANN DG. 1990. Diatoms: Biology and Morphology of the Genera. Cambridge University Press.

SALLEH A, RAHIM NA. 1994. Diatoms of the River Templer Malaysia. Diatom 9: 1–6.

SIMONSEN R. 1987. Atlas and catalogue of the diatom types of Friedrich Hustedt. Schweizerbart Science Publishers.

SKVORTZOW BW. 1937. Diatoms from the Philippines, I. Diatoms from the drinking water Balara, Rizal Province. Philippine Journal of Science 64(3): 287–298.

SOLAK CN, WOJTAL AZ, RYBAK M, YLLMAZ E. 2021. Distribution of *Didymosphenia, Gomphonema* and *Gomphosphenia* diatoms (Bacillariophyta) in Turkish inland waters. Oceanological and Hydrobiological Studies 50(2): 198–219. https://doi. org/10.2478/oandhs–2021–0018

UEYAMA S, KOBAYASI H. 1988. Two *Gomphonema* species with strongly capitate apices: *G. sphaerophorum* Ehr. and *G. pseudosphaerophorum*. In F. E. Round (Ed.), Proceeding of the 9th International Diatom Symposium (1986. Bristol: Biopress, Ltd. and Koeltz Scientific Books. p. 449–458.

VAN HEURCK HF. 1896. A treatise on the Diatomaceae. W. Wesley and Son. DOI: 10.5962/bhl.title.2002

VAN LANDINGHAM SL. 1978. Catalogue of the fossil and recent genera and species of diatoms and their synonyms. In: Part IV. Fragilaria through Naunema.

VENKATACHALAPATHY R, KARTHIKEYAN P. 2013. Benthic diatoms in river influenced by urban pollution, Bhavani Region, Cauvery River, South India. International Journal of Innovative Technology and Exploring Engineering 2(3): 206–210.

VOUILLOUD AA, SALA SE, AVELLANEDA MN, DUQUE SR. 2010. Diatoms from the Colombian and Peruvian Amazon: The genera *Encyonema, Encyonopsis* and *Gomphonema* (Cymbellales: Bacillariophyceae). Revista de Biologia Tropical 58(1): 45–62. DOI: 10.15517/rbt.v58i1.5193

WAN MAZNAH WO, MANSOR M. 2000. Periphytic algal composition in Pinang River Basin, a case study on one of the most polluted rivers in Malaysia. Journal Biosciences 11(1 & 2): 53–67.

WAN MAZNAH WO, MANSOR M. 2002. Aquatic pollution assessment based on attached diatom communities in the Pinang River Basin, Malaysia. Hydrobiologia 487: 229–241. DOI: 10.1023/A:1022942200740

WOJTAL A. 2003. Diatoms of the genus Gomphonema Ehr. (Bacillariophyceae) from a karstic stream in the Krakowsko-Częstochowska Upland. Acta Societatis Botanicorum Poloniae 72(3): 213–220. DOI: 10.5586/asbp.2003.028

WOLTERECK B. 1941. Islands and lakes of the Philippines. Int Rev of Gen Hydrobiology and Hydrography 41: 37.

YANA E, CHUNAM N, KAMLANGWONG A. 2019. Relationship between water properties with benthic diatom communities and trend of using for water quality assessment. The 2nd Suan Sumandha National and International Academic Conference on Science and Technology 6–142–6–151.

YU P, YOU Q, PANG W, CAO Y, BI Y, WANG Q. 2021. Development of periphytic diatom-based comprehensive diatom index for assessing the trophic status of lakes in the lower reaches of the Yangtze River, China. Water 13(24): 3570.

ZHANG L, YU P, KOCIOLEK JP, PANG W, WANG Q, YOU Q. 2020. *Gomphonema qingyiensis* sp. nov., a new freshwater species (Bacillariophyceae) from Qingyi River, China. Phytotaxa 474(1): 40–50. DOI: 10.11646/phytotaxa.474.1.4

APPENDICES

Appendix I. List of *Gomphonema* species observed in the Philippines (1937– to date).

List of *Gomphonema* species	Current valid name*	Place collected	Reference
cf. *abbreviatum* Agardh	*Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot	LUZON: Palawan (sample 25)	Podzorski and Håkansson (1987)
acuminatum Ehrenberg	Name as is	LUZON: Laguna, Laguna de Bay MINDANAO: Lanao del Sur (Uyaan Lake as *G. acuminata*)	Woltereck (1941); Antoine *et al.* (1997);
acuminatum f. *malayensis* Hustedt	Name as is	MINDANAO: Lanao del Sur (Uyaan Lake)	Woltereck (1941)
acuminatum var. *turris* (Ehrenberg) Cleve	*Gomphonema turris* Ehrenberg	LUZON: Palawan (sample 1)	Podzorski and Håkansson (1987)
affine Kützing	Name as is	LUZON: Rizal, Marikina (River); Laguna, Laguna de Bay	Antoine *et al.* (1997); Ohtsuka *et al.* (2009); this paper
angustatum Kützing	*angustatum* (Kützing) Rabenhorst	LUZON: Rizal, Manila (ponds in Bureau of Science); Batangas, Taal (Lake); Laguna, Laguna de Bay	Hustedt (1942); Antoine *et al.* (1997)
angustatum var. *linearis* Hustedt	Name as is	LUZON: Laguna, Laguna de Bay	Antoine *et al.* (1997)
***bohemicum* Reichelt & Fricke	*Gomphonema vibrio* var. *bohemicum* (Reichelt & Fricke) R. Ross	LUZON: Rizal, Marikina (River)	This paper
***brasiliense* subsp. *pacificum* G. Moser, Lange-Bertalot & Metzeltin	Name as is	LUZON: Rizal, Marikina (River)	This paper
bozenae Lange-Bertalot & E. Reichardt	Name as is	LUZON: Rizal, Marikina (River); Laguna, Laguna de Bay	Ohtsuka *et al.* (2009); this paper
***chinense* Liu & Kociolek	Name as is	LUZON: Rizal, Marikina (River)	This paper
clavatulum E. Reichardt	Name as is	LUZON: Laguna, Laguna de Bay	Ohtsuka *et al.* (2009)
clevei Fricke	*Gomphonema clevei* (Fricke) Gil	LUZON: Ifugao, Banaue (ponds); Batangas, Taal (Lake) Laguna, San Pablo (Yambo Lake)	Woltereck (1941); Hustedt (1942)
constrictum var. *capitatum* (Ehrenberg) Grunow	Name as is	VISAYAS: Leyte, Baybay City (Banahao-Palhi River)	Galinato and Evangelio (2016)
***contraturris* Lange-Bertalot & Reichardt	Name as is	LUZON: Rizal, Marikina (River)	This paper
***cuneolus* E. Reichardt	Name as is	LUZON: Rizal, Marikina (River)	This paper
***exilissimum* (Grunow) Lange-Bertalot & Reichardt	Name as is	LUZON: Rizal, Marikina (River)	This paper
gracile Ehrenberg emend. Van Heurck	*Gomphonema gracile* Ehrenberg	LUZON: Rizal, Malabon (Dagatdagatan swamp), Manila (ponds in Bureau of Science); Laguna, Laguna de Bay, Los Baños (Molawin Creek); Palawan (sample 3, dominant); Camarines Sur, Buhi (Lake and River); Oriental Mindoro, Naujan (Lake)	Hustedt (1942); Podzorski and Håkansson (1987); Antoine *et al.* (1997); Ohtsuka *et al.* (2009)
gracile var. *lanceolata* (Kützing) Cleve	*Gomphonema grunowii* R.M. Patrick & Reimer	LUZON: Palawan (samples 3, 6, 19)	Podzorski and Håkansson (1987)
grunowii R.M. Patrick & Reimer	Name as is	LUZON: Palawan (sample 1)	Podzorski and Håkansson (1987)
inaequilongum (H. Kobayasi) H. Kobayasi	Name as is	LUZON: Laguna, Laguna de Bay	Ohtsuka *et al.* (2009)

Appendix I. Continued . . .

List of *Gomphonema* species	Current valid name*	Place collected	Reference
insigne Gregory	Name as is	LUZON: Rizal, Manila (ponds in Bureau of Science); Batangas, Taal (Lake); Camarines Sur, Buhi (Lake and River) VISAYAS: Leyte, Ormoc (Danao Lake) MINDANAO: Lanao del Sur, Lanao Lake	Hustedt (1942)
***insigniforme* Reichardt & Lange-Bertalot	Name as is	LUZON: Rizal, Marikina (River)	This paper
intermedium Hustedt	Name as is	LUZON: Oriental Mindoro, Naujan (Lake) endemic, frequent MINDANAO: Agusan del Norte, Butuan City (Mainit Lake)	Woltereck (1941); Hustedt (1942)
intricatum Kützing	Name as is	LUZON: Laguna, Laguna de Bay; Palawan (sample 3)	Hustedt (1942); Podzorski and Håkansson (1987); Antoine *et al.* (1997)
***javanicum* Hustedt	Name as is	LUZON: Rizal, Marikina (River)	This paper
***kobayasii* Kociolek & Kingston	Name as is	LUZON: Rizal, Marikina (River)	This paper
lagenula Kützing	Name as is	LUZON: Rizal, Malabon (Dagatdagatan swamp), Marikina (River); Batangas, Taal (Lake); Camarines Sur, Buhi (Lake); Oriental Mindoro, Calapan (Caluangan Lake) MINDANAO: Lanao del Sur, Madamba (Lake); Cagayan de Oro (Lake): Sulu, Jolo (Lake)	Hustedt (1942); this paper
lanceolata Ehrenberg	*Gomphonema grunowii* R.M. Patrick & Reimer	LUZON: Laguna, Laguna de Bay	Antoine e*t al.* (1997)
lanceolatum C. Agardh	*Brebissonia lanceolata* (C. Agardh) R.K. Mahoney & Reimer	LUZON: Rizal, Malabon (Dagat-dagatan swamp), Quezon City (Balara), Manila (ponds in Bureau of Science); Batangas, Taal (Lake, Pansipit River); Laguna, Laguna de Bay, San Pablo (Bunot Lake); Camarines Sur, Buhi (Lake); Oriental Mindoro, Naujan (Lake), Calapan (Lake) VISAYAS: Leyte, Danao Lake	Skvortzow (1937); Hustedt (1942)
lanceolatum var. *turris* Hustedt	Name as is	LUZON: Ifugao, Banaue (ponds); Rizal, Malabon (Dagatdagatan swamp), Manila (ponds in Bureau of Science)	Woltereck (1941); Hustedt (1942)
lingulatum Hustedt	*Gomphosphenia grovei* var. *lingulata* (Hustedt) Lange-Bertalot	LUZON: Ifugao, Banaue (ponds); Laguna, Laguna de Bay	Woltereck (1941); Hustedt (1942)
longiceps Ehrenberg	*Gomphonema acuminatum* var. *longiceps* (Ehrenberg) N. Abarca & R. Jahn	LUZON: Laguna, Laguna de Bay	Antoine *et al.* (1997)
minusculum Krasske	Name as is	LUZON: Laguna, Laguna de Bay	Ohtsuka *et al.* (2009)
montanum var. *subclavatum* Grunow	*Gomphonema subclavatum* (Grunow) Grunow	LUZON: Rizal, Manila (Reservoir II)	Hustedt (1942)
olivaceum (Hornemann) Ehrenberg	*Gomphonella olivacea* (Hornemann) Rabenhorst	LUZON: Laguna, Laguna de Bay	Antoine *et al.* (1997)

Appendix I. Continued . . .

List of *Gomphonema* species	Current valid name*	Place collected	Reference
parvulum (Kützing) Kützing	Name as is	LUZON: Rizal, Marikina (River), Manila (ponds in Bureau of Science) Laguna, Laguna de Bay, Los Baños (ponds); Camariens Sur, Buhi (Lake and River); Oriental Mindoro, Naujan (Lake), Calapan (Caluangan Lake); Palawan MINDANAO: Lanao del Sur, Lanao Lake, Madamba (Uyaan Lake); Misamis Oriental, Cagayan de Oro City (Signal Lake); Sulu, Jolo (near the lake)	Hustedt (1942); Podzorski and Håkansson (1987); Antoine *et al.* (1997); this paper
productum (Grunow) Lange-Bertalot & E. Reichardt	Name as is	LUZON: Palawan (sample 11, 29)	Podzorski and Håkansson (1987)
pseudoaugur Lange-Bertalot	Name as is	LUZON: Laguna, Laguna de Bay	Ohtsuka *et al.* (2009)
***pseudosphaerophorum* Kobayasi	Name as is	LUZON: Rizal, Marikina (River)	This paper
pumilum (Grunow) E. Reichardt & Lange-Bertalot	Name as is	LUZON: Rizal, Marikina (River) MINDANAO: Lanao del Sur, Madamba (Uyaan Lake)	Hustedt (1942); this paper
punctatum Hustedt	Name as is	LUZON: Laguna, Laguna de Bay	Ohtsuka *et al.* (2009)
**cf. *qingyiensis* L-X. Zhang, P. Yu & Q-M. You	Name as is	LUZON: Rizal, Marikina (River)	This paper
sinestigma E. Reichardt, Jüttner & E. J. Cox	Name as is	LUZON: Laguna, Laguna de Bay	Ohtsuka *et al.* (2009)
sphaerophorum Ehrenberg	Name as is	LUZON: Rizal, Marikina (River); Palawan (sample 1)	Podzorski and Håkansson (1987); this paper
subclavatum (Grunow) Grunow	Name as is	VISAYAS: Leyte, Baybay City (Banahao-Palhi River)	Galinato and Evangelio (2016)
subtile Ehrenberg	Name as is	LUZON: Palawan (Sample 3, 6) VISAYAS: Leyte, Ormoc (Danao Lake) MINDANAO: Lanao del Sur, Madamba (Uyaan Lake)	Hustedt (1942); Podzorski and Håkansson (1987)
subtile var. *malayensis* Hustedt	*G. pantropicum* E. Reichardt	VISAYAS: Leyte, Ormoc City (Danao Lake) MINDANAO: Lanao del Sur, Madamba (Uyaan Lake)	Woltereck *et al.* (1941); Hustedt (1942)
***sundaense* E. Reichardt	Name as is	LUZON: Rizal, Marikina (River)	This paper
turris Ehrenberg	Name as is	LUZON: Laguna, Laguna de Bay	Antoine *et al.* (1997)
valentinica Nikolaev	*Gomphoseptatum aestuarii* (Clevei) Medlin	LUZON: Palawan (sample 21)	Podzorski and Håkansson (1987)

*Based on AlgaeBase (Guiry and Guiry 2023) and DiatomBase (Kociolek *et al.* 2023)
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