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Original Article

Diatom ecological guilds as environmental indicators for biomonitoring in a tropical river basin of Southeast Asia

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ABSTRACT. Functional traits are widely used in ecological studies to better understand diatom assemblages. This study examined the relationship between diatom ecological guilds (low-profile, high-profile, motile, and planktonic) and environmental parameters across 28 rivers and streams in the Tagoloan River Basin, Northern Mindanao, Philippines. The aim was to assess whether these guilds serve as effective indicators for biomonitoring. Canonical correspondence analysis (CCA) revealed a significant relationship ($p = 0.015$), indicating that phosphate (PO_4^{3-}), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), turbidity, pH, temperature, total dissolved solids (TDS), total suspended solids (TSS), conductivity, dissolved oxygen (DO), and flow influence diatom ecological guilds. The CCA explained 98.27% of the variance in two axes, demonstrating that diatom ecological guilds respond to environmental variables and may serve as useful indicators for river basin biomonitoring, which is useful for tropical countries like the Philippines where physicochemical analyses can be costly.

Keywords: biomonitoring, diatoms, diversity, ecological guilds, Tagoloan River Basin

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1. Introduction

Diatoms are considered one of the best bioindicators for aquatic systems (Bešta et al., 2015) because their assemblages are connected to the changes happening to their environment (Ladera et al., 2025; Porter et al., 2013). Most studies identify diatoms down to the species level to preserve the information shown by the assemblage and species complexes (Lane, 2007; Lange et al., 2016; Passy, 2007a). Some authors argued that identification to species level is critical because it improves classification within the ecoregion due to the presence of endemic and cosmopolitan diatoms (Morin et al., 2009; Ponader and Potapova, 2007). However, Rimet and Bouchez (2012) stated that genus-level identification is sufficient and has proven efficient and robust for bioassessment, as shown by other authors (Marcel et al., 2013; Pandey et al., 2017; Verleyen et al., 2009).

Using functional groups based on genus-level identification is another option to assess ecological quality (Berthon et al., 2011; Rimet and Bouchez, 2011) to complement biodiversity metrics (Pandey et al., 2017). This option reduces the strains in taxonomic identification, supplying a more cost and time effective method (Riato et al., 2017). Functional traits that reduce taxonomic resolution give good assessment on the pollution status much like species level resolution (Berthon et al., 2011; Passy, 2007b). A functional group is composed of organisms which share similar ecological features including morphology and physiology called functional traits (Tapolczai et al., 2016). Ecological guilds are examples of such groups which is defined as a group of taxa sharing the same environ-

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ment and utilize available resources similarly through various adaptations to abiotic factors (B-Béres et al., 2014; Passy, 2007b; Rimet and Bouchez, 2011) which can be applied to diatoms. These functional traits are used as adaptive strategies and growth morphologies by diatoms to provide more interpretation on the diatom assemblage variation. The use of such biological traits provides more robust ecological profiles because diatoms occur in biofilms. Understanding biofilm structure enhances the ecological interpretation of diatom guilds in biomonitoring, as guild composition reflects how diatoms interact with and adapt to environmental conditions within these structured communities (Cibic et al., 2012).

Passy (2007b) introduced three ecological guilds. The low-profile guild was comprised of species of short stature which include prostrate, adnate, erect, solitary centrics and slow-moving species (e.g., *Achnanthes*, *Achnanthidium*, *Amphora*, *Cocconeis*, *Cyclotella*, *Cymbella*, *Hannaea*, *Meridion*, *Opephora*, and *Reimeria*). Low-profile resists the change done by physical disturbance but cannot that of nutrient enrichment. The high-profile guild was composed of species of tall stature which include erect, filamentous, branched, chain-forming, tube-forming, stalked and colonial centrics (e.g., *Diatoma*, *Ellerbeckia*, *Eunotia*, *Fragilaria*, *Gomphoneis*, *Gomphonema*, *Melosira* and *Synedra*). Passy further explained their ability to make colonies allows them to exploit resources which are unavailable to the low-profile guild. High-profile guild does not resist the change done by physical disturbance but resists that of nutrient enrichment. The motile guild was constituted of fast-moving species from the *Navicula*, *Nitzschia*, *Sellaphora*, and *Surirella* genera. The motile guild shows similar pattern to that of high-profile but its members are able to move to a more suitable habitat. Rimet and Bouchez (2011) added a planktonic guild which are primarily diatoms which have adapted to the lentic environment through their adaptations that enable them to withstand sedimentation. Since different guilds show varying tolerances to nutrient enrichment, they can serve as effective indicators of trophic states. The high-profile and motile guilds, which are not limited by nutrients, may dominate in eutrophic waters, where nutrient levels are high (Passy, 2007b). On the other hand, the low-profile guild, which is sensitive to nutrient enrichment, may be more abundant in oligotrophic or less nutrient-rich environments (Passy, 2007b). The planktonic guild's presence can indicate slower-moving or standing waters where sedimentation is a concern (Rimet and Bouchez, 2011).

In order to assess the water quality and the disturbances in streams, diatom ecological guilds have been used in biomonitoring studies around the world (B-Béres et al., 2017; Marcel et al., 2017; Riato et al., 2017). However, no study was still done about using diatom functional-based approach as a means of assessing the conditions of aquatic systems in the Philippines. This study aims to evaluate the relationship between diatom ecological guilds and environmental variables, and to determine whether they can be used for biomonitoring in the Tagoloan River Basin.

2. Materials and Methods

Samples were collected at 28 rivers and streams of the Tagoloan River Basin (Fig. 1), encompassing the municipalities of Tagoloan, Villanueva, and Claveria in Misamis Oriental; and Malitbog, Manolo Fortich, Sumilao, Impasug-ong, and Malaybalay City in Bukidnon from August until December 2018. Three sampling points were established, representing the upstream, midstream and downstream regions of each river or tributary. In each sampling point, there were three replicates where the measurement of physical and chemical parameters and the collection of diatoms were done. Water depth (m) and the width (m) of the rivers and streams were measured using a meter stick while water flow (m/s) was measured using a drogue and a stopwatch. Water temperature (ºC), pH, total dissolved solids (mg/L), conductivity (μs/cm) and dissolved oxygen (mg/L) were measured in situ using a portable multiparameter digital meter (HACH water ecology, limnology Model AL-36DT). Water samples of 1000 mL were kept in coolers at 4 ºC while being transported to the laboratory for concentration measurements (mg/L) of nitrite (NO_2^-), nitrate (NO_3^-), phosphate (PO_4^{3-}), ammonium (NH_4^+), iron (Fe^+), biological oxygen demand (BOD_5), total suspended solids (TSS),

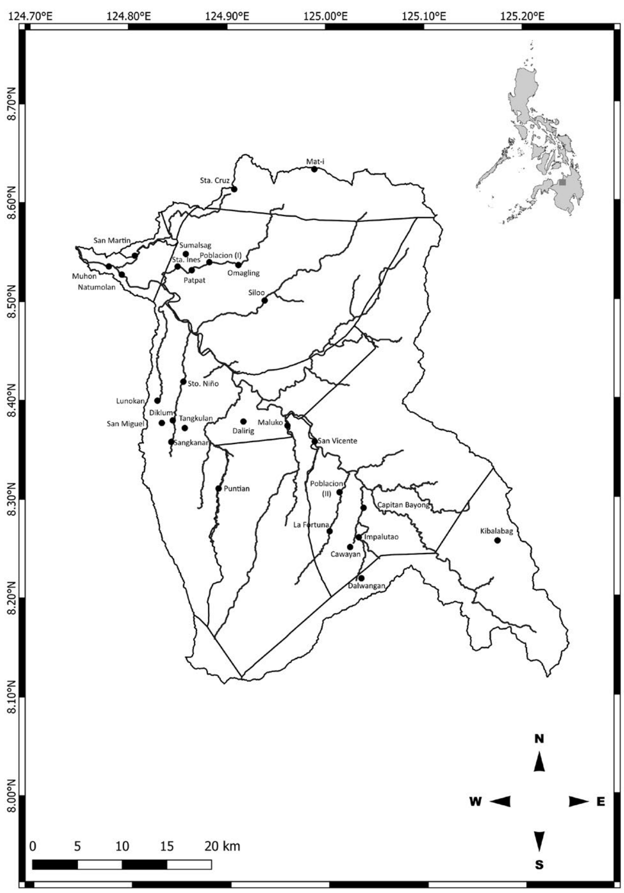

Fig.1. The sampling sites in the Tagoloan River Basin in the region of Northern Mindanao, Philippines. Black inner squiggly lines: The rivers and streams in the Tagoloan River Basin. Black dots: The sampling sites in the Tagoloan River Basin.

and water hardness using the guidelines of the Standard Methods for the Examination of Water and Wastewater 18th Edition (American Public Health Association et al., 2012). Turbidity (NTU) was measured in the laboratory with the Thermo Scientific Genesys 10 UV-Visible spectrometer.

Ten cobble-sized stones were collected in each one of the three replicate points in each sampling site, and were scrubbed with a clean toothbrush covering a surface area of 10 cm^2. The diatoms collected were placed in amber bottles fixed with 5% buffered solution made of 37% formaldehyde diluted with distilled water. In the laboratory, the diatom valves were cleaned and prepared using the hot hydrogen-peroxide method (EN13946:2003) before embedding in a Naphrax synthetic resin. Swift Optical M10DB-MP Phase Contrast microscope with 1000x magnification was then used for the counting and identification of 400 diatom frustules (EN 14407:2004). Identification down to genus level was done using the taxonomic keys of Gell (1999), Taylor et al. (2007), and other specialized keys as needed. There were 756 slides of diatom samples that were analyzed with parallel environmental parameters collected.

The identified diatom genera were classified according to the ecological guilds of Passy (2007b) and Rimet and Bouchez (2011) as shown in Table 1. Principal Component Analysis (PCA) was used to identify the most influential environmental variables (Stenger-Kovács et al., 2013), with 12 environmental variables determined to be the key factors. Canonical correspondence analyses (CCA) were conducted to examine the relationship between key environmental variables (identified through PCA) and diatom assemblages, both in terms of taxonomic composition and ecological guild structure. Environmental variables were incorporated into the CCA using a weighted averaging approach. Multivariate analysis was done using the PAST software version 4.16 (Hammer, 2023).

3. Results

There were 29 identified diatom genera in the 28 sampling areas of the Tagoloan River Basin; of which *Navicula* (19.24%), *Cocconeis* (16.34%), and *Achnanthidium* (12.78%) were the most abundant genera (Table 2). Across the said sampling areas, *Cocconeis* was the most abundant in 12 sites, followed by *Navicula* in 7 sites; *Achnanthidium* in 3 sites; *Gomphonema* in 2 sites; and *Encyonema*, *Fragilaria*, *Gomphoneis*, and *Nitzschia* in 1 site each (Table 3). In terms of diversity values, the sampling areas had a Simpson's index of diversity (1-D) ranging from 0.7727 (Lunokan) to 0.8907 (Muhon), indicating that the sites sampled were diverse in diatom assemblages (Table 3).

Table 1. Taxa assignment to the four ecological guilds adapted from Passy (2007b) and Rimet and Bouchez (2011).

Ecological guilds	Guild Description	Taxa composition
Low-profile	Comprised of species of short stature, including prostrate (species with their whole valve area directly attached to the substrate), adnate (species with their apex attached in parallel to the substrate), erect (species with perpendicular attachment to the substrate), solitary centrics, and slow- moving species	*Achnanthes* Bory 1822 *Achnanthidium* Kutzing 1844 *Amphora* Ehrenberg ex Kutzing 1844 *Cocconeis* Ehrenberg 1837 *Cymbella* Agardh 1830 *Diploneis* Cleve 1894 *Planothidium* Round and Bukhtiyarova 1996
High-profile	Comprised of species of tall stature, including erect, filamentous, branched, chain-forming, tubeforming, stalked, and colonial centrics	*Encyonema* Kutzing 1833 *Eunotia* Ehrenberg 1837 *Fragilaria* Lyngbye 1819 *Frustulia* Rabenhorst 1583 *Gomphoneis* Cleve 1894 *Gomphonema* Ehrenberg 1832 *Melosira* Agardh 1824 *Pleurosira* San Leon 1848
Motile	Comprised of species which are capable of motility in sediments	*Bacillaria* Gmelin 1791 *Epithemia* Kutzing 1844 *Gyrosigma* Hassall 1845 *Hantzschia* Grunow 1877 *Luticola* Mann 1990 *Navicula* Bory 1822 *Nitzschia* Hassall 1845 *Pinnularia* Ehrenberg 1843 *Rhopalodia* Muller 1895 *Sellaphora* Mereschkowsky 1902 *Stauroneis* Ehrenberg 1843 *Surirella* Turpin 1828 *Tryblionella* Smith 1853
Planktonic	Corresponds to taxa adapted to lentic environments with morphological adaptations that enable them to resist sedimentation	*Cyclotella* Kutzing ex Brebisson 1838

Out of the 17 physical and chemical parameters measured, 12 variables (NO_2^-, NO_3^-, PO_4^+, NH_4^+, turbidity, pH, temperature, conductivity, flow, TDS, TSS, and DO) turned out to be the main components based on the PCA done (Fig. 2). The first two axes of the PCA explained 96.82% of variance. The dominant factors were TSS (0.9749), flow (0.1185), TDS (0.0839), pH (0.0543), and conductivity (0.0456).

Tables 4 to 6 show the range and mean values of the measured physical and chemical conditions in the 28 sampling areas. Not all rivers and tributaries sampled in the river basin received a water body classification from the Department of Environment and Natural Resources (DENR) Region 10. However, Tagoloan River which is a major river, and Malitbog River which is a principal river, both received a Class A classification which meant that they are intended as sources of water supply requiring conventional treatment to meet the national standards (DENR Administrative Order 2016-08, 2016). Going by such classification, the rivers of the Tagoloan River Basin can be considered as Class A. Based on the water quality guidelines (WQG) by DENR, some sites had measurements of phosphate, nitrate, pH, TSS, and temperature which were beyond the standard values. These are indicated by the values in red.

The 28 sampling areas can be grouped according to the relative abundances of the ecological guilds (Table 7). Seventeen of the sampling areas were primarily composed of low-profile diatoms (Capitan Bayong, Dalirig, Impalutao, Kibalabag, La Fortuna, Lunokan, Maluko, Muhon, Omagling, Poblacion (I), Puntian, Sangkanan, San Martin, San Vicente, Silo-o, Sto. Niño, and Sumalsag) while 8 sites were mainly composed of motile diatoms (Cawayan, Dalwangan, Diklum, Natumolan, Patpat, Poblacion (II), San Miguel, and Sta. Ines). Three areas were mainly defined by

Table 2. Relative abundance of diatom genera in the Tagoloan River Basin. Values in red indicate the top three most abundant genera.

Diatom Genera	Relative Abundance (%)
Achnanthes	4.15
Achnanthidium	12.78
Amphora	0.86
Bacillaria	0.01
Cocconeis	16.34
Cyclotella	0.27
Cymbella	2.94
Diploneis	0.01
Encyonema	2.70
Epithemia	0.02
Eunotia	0.14
Fragilaria	3.69
Frustulia	0.31
Gomphoneis	5.97
Gomphonema	9.96
Gyrosigma	0.91
Hantzschia	0.08
Luticola	2.80
Melosira	0.77
Navicula	19.24
Nitzschia	8.52
Pinnularia	1.17
Planothidium	3.60
Rhopalodia	0.15
Sellaphora	0.01
Stauroneis	1.05
Surirella	0.88
Pleurosira	0.06
Tryblionella	0.62

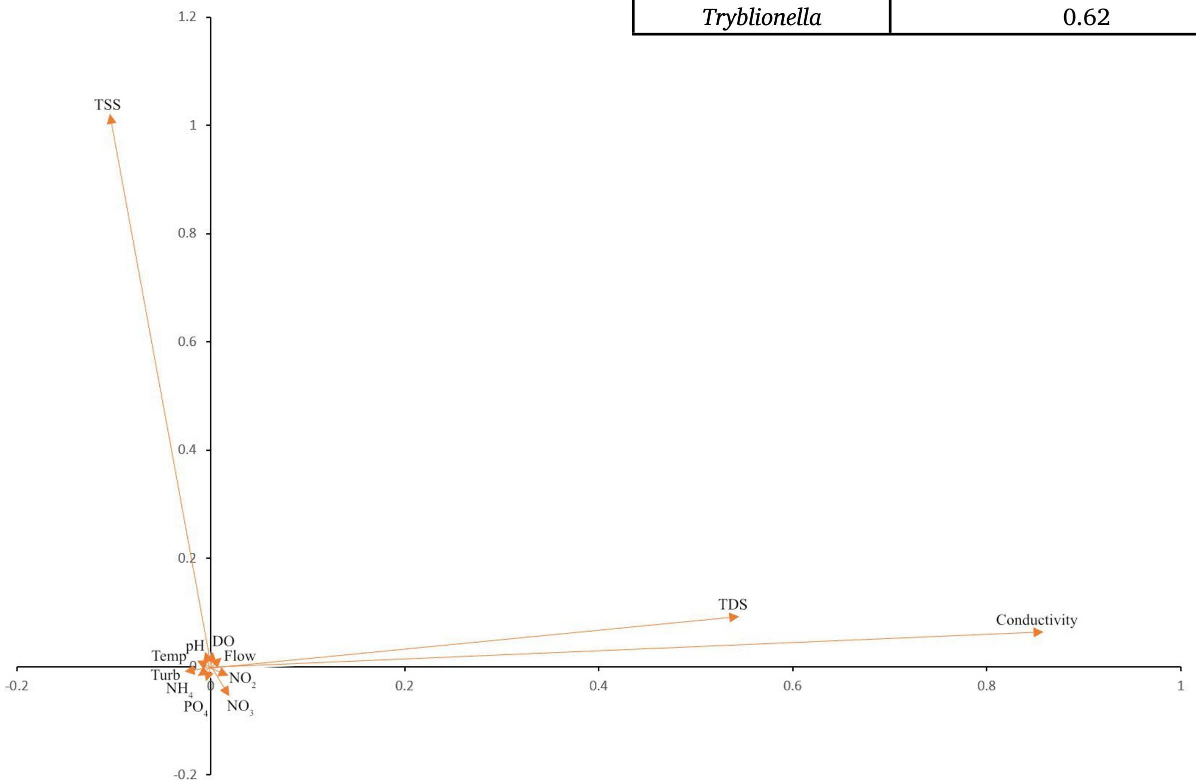

Fig.2. Principal component analysis diagram with ordination of axis 1 and 2 of measured environmental variables of the Tagoloan River Basin (Axis 1: 78.68%; Axis 2: 19.59%).

Table 3. Dominant diatom genera and their relative abundances, and Simpson's index of diversity (1-D) values in each of the 28 sampling areas of the Tagoloan River Basin.

Sampling Area	Dominant Genera	Relative Abundance (%)	Simpson (1-D)
Kibalabag	*Nitzschia*	18.78	0.8690
Mat-i	*Encyonema*	34.00	0.8164
Dalwangan	*Fragilaria*	18.78	0.8835
Cawayan	*Gomphoneis*	26.42	0.8470
La Fortuna	*Cocconeis*	25.36	0.8498
Impalutao	*Cocconeis*	24.78	0.8524
Sta. Cruz	*Navicula*	28.47	0.8294
Puntian	*Cocconeis*	23.94	0.8492
Sangkanan	*Navicula*	19.08	0.8599
San Miguel	*Gomphonema*	23.97	0.8314
Capitan Bayong	*Cocconeis*	25.94	0.8338
Tangkulan	*Gomphonema*	29.72	0.8002
Poblacion (I)	*Cocconeis*	26.19	0.8461
Diklum	*Navicula*	35.08	0.8050
Lunokan	*Cocconeis*	42.28	0.7727
Sto. Niño	*Cocconeis*	26.06	0.8514
Dalirig	*Cocconeis*	22.08	0.8801
San Vicente	*Cocconeis*	28.06	0.8336
Maluko	*Cocconeis*	29.00	0.8320
Silo-o	*Cocconeis*	32.28	0.7949
Omagling	*Cocconeis*	25.47	0.8365
Poblacion (II)	*Achnanthidium*	28.94	0.8239
Sumalsag	*Achnanthidium*	29.44	0.8281
Patpat	*Navicula*	22.69	0.8789
Sta. Ines	*Navicula*	28.39	0.8565
San Martin	*Navicula*	19.17	0.8759
Muhon	*Achnanthidium*	17.14	0.8907
Natumolan	*Navicula*	22.56	0.8822

high-profile diatoms (Mat-i, Sta. Cruz, and Tangkulan). Since the planktonic guild was only represented by one genus, 8 of the sampling sites had no planktonic diatoms.

A significant relationship between the 12 environmental variables and the diatom ecological guilds was indicated in the CCA (Fig. 3). The correlation between the guilds and environmental variables across the first two axes was 98.27%, with statistical significance confirmed by a Monte Carlo permutation test (N = 999, p = 0.015). The low-profile guild was positively associated with DO, pH, and conductivity and was negatively associated with NO_3, NO_2, and turbidity. In contrast, the high-profile guild was positively associated with turbidity and was negatively associated with TDS, DO, and conductivity. The motile guild was positively associated with NO_3, NO_2, PO_4, TSS, and temperature; and was negatively associated with DO and conductivity. The planktonic guild was positively associated with TDS and conductivity and was negatively associated with NH_4, flow, and turbidity.

In terms of diatom generic composition (Fig. 4), low-profile guild members were strongly correlated with DO and flow, especially *Achnanthes* (Achn) while *Cocconeis* (Cocc) and *Planothidium* (Plano) had a weak correlation with flow and DO. *Achnanthidium* (Achndm) and *Cymbella* (Cymb) were weakly associated with conductivity, TDS, and TSS while *Amphora* (Amph) and *Diploneis* (Dipl) were negatively associated with temperature. *Pleurosira* (Pleura), a member of the high-profile guild, was strongly positively correlated with PO_4^{3-} and turbidity while *Gomphonema* (Gopma) was positively associated with NO_2^- and NO_3^-. *Eunotia* (Euno) was weakly associated with NH_4^+ and pH while *Frustulia* (Frus) was weakly associated with conductivity, TDS, and TSS. *Encyonema* (Ency), *Fragilaria* (Frag), *Gomphoneis* (Gomeis), and *Melosira* (Melo) were all positively associated with DO and flow. The motile guild was correlated with high NO_2^- and NO_3^-, especially *Bacillaria* (Bacil), *Pinnularia* (Pinn), and *Surirella* (Suri). *Navicula* (Navi) and *Stauroneis* (Stau) were positively correlated with PO_4^{3-}, turbidity, NO_3^-, and NO_2^-. *Hantzschia* (Hantz) was positively associated with PO_4^{3-} and flow while *Sellaphora* (Sella) was positively correlated with PO_4^{3-} and turbidity. *Epithemia* (Epit), *Luticola* (Luti), and *Nitzschia* (Nitz) were strongly positively associated with DO and flow. On the other hand, *Gyrosigma* (Gyro), *Rhopalodia* (Rhop), and *Tryblionella* (Tryb) had a weak correlation with conductivity, TDS, and TSS. *Cyclotella* (Cyclo), the lone member of the planktonic guild, was strongly positively correlated with DO and flow.

Table 4. Range and mean physicochemical conditions (Flow, pH, Temperature, and TDS) of sampled rivers and streams. Values in red indicate that they are above or below the standard value or are out of range.

Sampling Area	Parameter							
	Flow (m/s)		pH Standard range = 6.50 - 8.50		Temperature (ºC) Standard range = 26.00 - 30.00		TDS (mg/L)	
	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)
Kibalabag	3.90–14.25	8.44 ± 0.74	7.96–8.76	8.37 ± 0.30	20.8–22.30	21.44 ± 0.55	177.00–250.00	205.44 ± 28.77
Mat-i	1.35–6.19	3.63 ± 0.69	7.00–7.90	7.36 ± 0.25	21.50–22.10	21.57 ± 0.20	34.00–78.00	41.33 ± 13.86
Dalwangan	1.53–9.53	4.44 ± 0.68	7.20–8.18	7.70 ± 0.32	23.30–24.50	24.00 ± 0.46	167.00–170.00	168.11 ± 0.93
Cawayan	1.80–6.80	3.68 ± 0.00	7.64–7.79	7.72 ± 0.05	26.20–28.10	26.76 ± 0.63	60.00–65.00	61.11 ± 1.54
La Fortuna	1.60–6.80	3.76 ± 0.58	7.83–8.09	7.94 ± 0.08	25.90–26.70	26.31 ± 0.25	51.00–59.00	52.44 ± 2.51
Impalutao	1.84–6.00	3.72 ± 0.18	7.16–8.10	7.76 ± 0.41	23.00–25.60	24.03 ± 0.85	103.00–133.00	114.67 ± 14.16
Sta. Cruz	2.00–6.00	3.86 ± 0.30	7.70–7.78	7.75 ± 0.03	23.30–24.00	23.64 ± 0.26	47.00–54.00	48.11 ± 2.26
Puntian	0.22–7.47	2.84 ± 0.15	7.70–7.78	5.73 ± 0.02	23.30–24.00	22.88 ± 0.51	47.00–54.00	103.67 ± 0.50
Sangkanan	2.08–3.45	2.62 ± 0.73	7.67–7.79	7.73 ± 0.04	23.10–24.00	23.58 ± 0.26	56.00–68.00	65.78 ± 3.73
San Miguel	3.75–4.60	4.04 ± 0.48	7.07–7.31	7.16 ± 0.07	25.20–26.00	25.53 ± 0.24	110.00–121.00	116.11 ± 3.92
Capitan Bayong	0.72–4.59	2.77 ± 0.70	8.28–8.42	8.37 ± 0.04	22.60–24.40	23.26 ± 0.61	144.00–200.00	150.44 ± 18.59
Tangkulan	2.47–10.5	4.47 ± 1.60	7.57–7.84	7.65 ± 0.09	25.40–26.30	25.72 ± 0.39	78.00–115.00	82.67 ± 12.13
Poblacion (I)	1.68–4.41	2.81 ± 0.32	8.46–8.55	8.50 ± 0.03	24.60–26.10	25.13 ± 0.55	132.00–145.20	134.69 ± 4.69
Diklum	3.56–5.80	4.92 ± 1.19	6.79–7.08	6.97 ± 0.09	25.70–26.70	26.12 ± 0.41	57.00–82.00	63.22 ± 8.38
Lunokan	1.93–12.00	6.11 ± 1.66	7.87–8.40	8.07 ± 0.14	26.40–27.80	26.61 ± 0.46	247.00–272.00	250.89 ± 7.96
Sto. Nino	1.65–2.97	2.52 ± 0.75	7.95–8.15	8.08 ± 0.06	23.90–24.20	24.09 ± 0.09	139.00–144.00	140.33 ± 1.87
Dalirig	1.60–11.00	6.42 ± 0.82	7.71–8.21	8.06 ± 0.16	24.00–24.50	24.22 ± 0.19	293.00–346.00	301.00 ± 16.96
San Vicente	0.69–6.47	2.58 ± 0.64	5.73–5.79	5.76 ± 0.02	27.60–39.60	30.06 ± 3.68	163.00–167.00	166.11 ± 1.27
Maluko	0.40–16.00	4.04 ± 3.27	7.21–7.86	7.68 ± 0.21	22.50–27.70	23.34 ± 1.65	134.00–158.00	140.78 ± 9.46
Silo-o	1.00–4.60	2.71 ± 0.62	8.28–8.50	8.41 ± 0.07	22.80–26.80	24.40 ± 1.39	123.00–204.00	176.89 ± 22.25
Omagling	1.37–19.00	3.33 ± 0.66	8.58–8.69	8.63 ± 0.04	26.70–28.40	27.21 ± 0.53	165.00–189.00	175.22 ± 9.64
Poblacion (II)	1.05–5.67	2.18 ± 0.56	7.64–8.02	7.84 ± 0.17	24.50–24.70	24.60 ± 0.09	506.00–508.00	506.67 ± 1.00
Sumalsag	1.86–4.64	3.18 ± 1.39	7.74–8.16	7.97 ± 0.15	26.60–28.20	27.47 ± 0.55	495.00–554.00	513.33 ± 17.72
Patpat	3.30–4.43	3.91 ± 0.51	7.25–8.00	7.76 ± 0.22	26.10–27.30	26.63 ± 0.41	169.00–171.00	170.00 ± 0.71
Sta. Ines	2.45–3.45	2.89 ± 0.51	6.78–8.00	7.68 ± 0.36	24.20–25.50	24.54 ± 0.39	174.00–189.00	180.89 ± 3.82
San Martin	0.62–5.63	2.47 ± 1.13	8.72–8.82	8.79 ± 0.03	28.40–28.70	28.59 ± 0.11	191.00–195.00	192.00 ± 1.22
Muhon	2.90–10.75	5.44 ± 0.71	8.73–9.05	8.83 ± 0.11	29.40–30.30	29.91 ± 0.35	209.00–231.00	214.67 ± 6.91
Natumolan	1.70–6.16	4.03 ± 0.53	8.88–9.97	9.11 ± 0.33	29.20–30.40	29.53 ± 0.39	195.00–203.00	197.89 ± 2.85

Table 5. Range and mean of physicochemical conditions (Conductivity, DO, Turbidity, and TSS) of sampled rivers and streams. Values in red indicate that they are above or below the standard value or are out of range.

Sampling Area	Parameter							
	Conductivity (µs/cm)		DO (mg/L) Standard minimum value = 5.00		Turbidity (NTU)		TSS (mg/L) Standard value = 50.00	
	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)
Kibalabag	176.90–250.00	205.56 ± 28.71	6.44–7.53	7.01 ± 0.41	0.00–6.00	1.00 ± 1.94	0.56.–795.40	262.01 ± 259.20
Mat-i	33.90–45.60	36.90 ± 3.57	7.18–7.33	7.26 ± 0.05	10.00–10.00	10.00 ± 0.00	1.80–281.28	98.81 ± 115.04
Dalwangan	167.60–172.80	169.17 ± 1.70	6.43–6.81	6.65 ± 0.15	0.30–6.00	1.48 ± 1.77	1.10–220.96	41.61 ± 70.86
Cawayan	57.20–62.80	58.51 ± 1.68	7.12–7.66	7.31 ± 0.19	2.00–6.00	3.22 ± 1.20	5.73–375.12	146.68 ± 140.57
La Fortuna	48.80–54.60	50.24 ± 1.73	7.27–7.40	7.31 ± 0.04	0.00–1.00	0.67 ± 0.50	1.08–232.64	29.80 ± 76.10
Impalutao	98.30–127.30	109.70 ± 13.27	6.31–7.60	7.19 ± 0.49	1.00–1.00	1.00 ± 0.00	2.22–126.78	45.48 ± 45.83
Sta. Cruz	45.00–48.60	45.88 ± 1.07	7.46–7.70	7.61 ± 0.09	7.00–10.00	8.33 ± 1.32	5.47–258.09	69.87 ± 99.20
Puntian	45.00–48.60	99.09 ± 0.86	7.46–7.70	7.46 ± 0.09	7.00–10.00	8.00 ± 1.73	5.47–258.09	18.49 ± 25.49
Sangkanan	62.70–67.60	64.27 ± 1.49	7.44–7.56	7.51 ± 0.04	5.00–6.00	5.67 ± 0.50	8.06–271.38	127.10 ± 100.17
San Miguel	105.20–116.30	111.23 ± 3.70	6.03–6.49	6.27 ± 0.18	6.00–18.00	11.00 ± 4.77	21.20–1091.00	478.11 ± 373.57
Capitan Bayong	136.30–140.00	137.79 ± 0.98	7.82–8.03	7.92 ± 0.07	0.00–1.00	0.78 ± 0.44	7.31–237.96	92.61 ± 97.66
Tangkulan	116.42–171.64	123.38 ± 18.11	7.04–7.24	7.15 ± 0.08	13.00–17.00	14.00 ± 1.41	14.81–89.11	45.42 ± 28.91
Poblacion (I)	126.60–137.90	129.23 ± 4.10	7.62–7.85	7.79 ± 0.07	1.00–1.00	1.00 ± 0.00	3.68–117.20	17.27 ± 37.49
Diklum	85.07–122.39	94.36 ± 12.50	7.01–7.12	7.05 ± 0.04	28.00–54.00	43.89 ± 6.97	29.20–48.80	37.60 ± 6.93
Lunokan	368.66–405.97	374.46 ± 11.88	6.80–7.08	7.01 ± 0.08	1.00–4.00	2.11 ± 1.27	2.33–127.26	38.29 ± 41.03
Sto. Nino	133.70–140.90	135.28 ± 2.61	7.41–7.61	7.53 ± 0.06	2.00–4.00	3.22 ± 0.97	16.60–752.00	350.16 ± 306.52
Dalirig	437.31–516.42	449.25 ± 25.31	7.41–7.64	7.54 ± 0.08	1.00–1.00	1.00 ± 0.00	3.22–119.22	46.48 ± 42.80
San Vicente	157.90–161.40	159.87 ± 1.07	7.30–7.68	7.49 ± 0.13	2.00–6.00	3.22 ± 1.20	8.47–91.33	19.61 ± 27.02
Maluko	200.00–235.82	210.12 ± 14.12	7.80–8.02	7.93 ± 0.08	1.00–2.00	1.11 ± 0.33	4.42–942.74	113.04 ± 311.17
Silo-o	167.10–194.30	176.34 ± 9.16	7.48–7.89	7.76 ± 0.14	0.00–7.00	1.78 ± 2.28	6.07–12.67	8.93 ± 2.36
Omagling	157.60–180.00	166.62 ± 8.52	7.37–7.67	7.54 ± 0.09	0.00–1.00	0.22 ± 0.44	1.26–12.07	7.00 ± 2.87
Poblacion (II)	755.22–758.21	756.22 ± 1.49	7.41–7.43	7.42 ± 0.01	1.00–4.00	1.56 ± 1.01	2.11–121.20	55.82 ± 36.88
Sumalsag	738.81–826.87	766.17 ± 26.45	7.25–7.58	7.41 ± 0.12	1.00 -1.00	1.00 ± 0.00	11.16–78.84	38.55 ± 22.89
Patpat	252.24–255.22	253.73 ± 1.06	7.13–7.55	7.39 ± 0.13	5.00–10.00	7.44 ± 1.67	5.89–26.77	13.32 ± 5.73
Sta. Ines	259.70–282.09	269.98 ± 5.71	7.62–7.85	7.75 ± 0.07	5.00–11.00	7.89 ± 1.69	10.84–21.16	15.99 ± 3.70
San Martin	183.80–189.70	185.49 ± 1.74	7.67–7.88	7.82 ± 0.06	7.00–10.00	8.00 ± 0.87	27.80–551.60	167.30 ± 185.76
Muhon	105.60–210.50	194.18 ± 33.36	7.40–10.96	8.76 ± 1.26	2.00–8.00	5.33 ± 2.18	35.20–106.80	68.06 ± 28.76
Natumolan	188.40–194.80	190.41 ± 2.29	8.34–11.22	9.55 ± 1.07	1.00–2.00	1.56 ± 0.53	7.78–102.67	23.35 ± 30.68

Table 6. Range and mean of physicochemical conditions (NO_2^-, NO_3^-, NH_4^+, and PO_4^{3-}) of sampled rivers and streams. Values in red indicate that they are above or below the standard value or are out of range.

Sampling Area	Parameter							
	NO_2^- (mg/L)		NO_3^- (mg/L) Standard value = 7.00		NH_4^+ (mg/L)		PO_4^{3-} (mg/L) Standard value = <0.05	
	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)	Range	Mean (sd)
Kibalabag	0.001–0.015	0.00 ± 0.00	1.00–13.00	6.33 ± 3.61	0.03–0.13	0.073 ± 0.04	0.01–0.02	0.01 ± 0.00
Mat-i	0.012–0.017	0.01 ± 0.00	1.00–2.00	1.67 ± 0.50	0.2–1.44	0.71 ± 0.56	0.03–0.09	0.05 ± 0.03
Dalwangan	0.001–0.016	0.01 ± 0.01	1.00–11.00	4.22 ± 2.95	0.01–0.12	0.04 ± 0.04	0.01–0.016	0.01 ± 0.00
Cawayan	0.021–0.029	0.02 ± 0.00	2.00–10.60	5.51 ± 2.74	0.01–0.10	0.04 ± 0.04	0.006–0.027	0.01 ± 0.01
La Fortuna	0.02–0.024	0.02 ± 0.00	1.00–9.00	5.56 ± 2.13	0.01–0.01	0.01 ± 0.00	0.002–0.218	0.04 ± 0.08
Impalutao	0.007–0.025	0.02 ± 0.01	1.00–5.00	3.11 ± 1.69	0.01–0.08	0.02 ± 0.02	0.004–0.051	0.01 ± 0.01
Sta. Cruz	0.013–0.14	0.06 ± 0.06	4.00–11.00	8.00 ± 3.12	0.03–0.25	0.17 ± 0.11	0.01–0.06	0.03 ± 0.02
Puntian	0.013–0.14	0.01 ± 0.00	4.00–11.00	7.44 ± 3.13	0.03–0.25	0.21 ± 0.02	0.01–0.06	0.01 ± 0.00
Sangkanan	0.017–0.02	0.02 ± 0.00	5.00–12.00	8.00 ± 2.83	0.10–0.30	0.16 ± 0.07	0.04- 0.06	0.05 ± 0.01
San Miguel	0.017–0.117	0.08 ± 0.03	30.00–34.00	32.44 ± 1.33	0.10–0.26	0.17 ± 0.07	0.033–0.056	0.04 ± 0.01
Capitan Bayong	0.02–0.025	0.02 ± 0.00	8.00–11.00	9.00 ± 1.00	0.01–0.06	0.03 ± 0.02	7.82–8.03	0.01 ± 0.00
Tangkulan	0.008–0.013	0.01 ± 0.00	1.00–5.00	4.11 ± 1.76	0.00–0.30	0.16 ± 0.09	0.01–0.18	0.07 ± 0.06
Poblacion (I)	0.017–0.024	0.02 ± 0.00	1.00–7.00	3.78 ± 2.54	0.01–0.07	0.02 ± 0.03	0.013–0.035	0.02 ± 0.01
Diklum	6.00–34.00	18.44 ± 10.50	45.00–200.00	106.44 ± 46.87	0.40–0.90	0.67 ± 0.16	0.68–15.30	8.34 ± 5.88
Lunokan	0.005–0.009	0.07 ± 0.00	6.00–23.00	15.78 ± 7.55	0.30–4.90	1.41 ± 1.40	0.35–0.59	0.43 ± 0.07
Sto. Nino	0.013–0.021	0.02 ± 0.00	5.00–15.00	8.11 ± 3.55	0.10–0.20	0.13 ± 0.05	0.021–0.048	0.03 ± 0.01
Dalirig	0.002–0.007	0.00 ± 0.00	4.00–56.00	32.11 ± 21.45	0.00–0.20	0.13 ± 0.09	0.03–0.23	0.11 ± 0.09
San Vicente	0.024–0.028	0.03 ± 0.00	7.00–15.00	10.00 ± 2.24	0.20–0.26	0.23 ± 0.03	0.017–0.02	0.02 ± 0.00
Maluko	0.005–0.30	0.04 ± 0.01	3.00–20.00	12.44 ± 6.67	0.00–0.50	0.17 ± 0.25	0.16–0.40	0.24 ± 0.07
Silo-o	0.012–0.017	0.01 ± 0.00	27.40–45.00	36.36 ± 5.80	0.01–1.10	0.30 ± 0.47	0.047–0.089	0.07 ± 0.01
Omagling	0.009–0.014	0.01 ± 0.00	28.20–42.50	33.68 ± 3.90	0.01–1.70	0.57 ± 0.85	0.014–0.026	0.02 ± 0.00
Poblacion (II)	1.00–19.00	7.56 ± 6.52	10.00–50.00	19.89 ± 15.28	0.00–0.50	0.17 ± 0.18	0.01–0.07	0.03 ± 0.02
Sumalsag	1.00–7.00	4.67 ± 2.00	14.00–35.00	26.67 ± 6.56	0.00–0.20	0.08 ± 0.06	0.01–0.05	0.03 ± 0.02
Patpat	1.00–1.00	1.00 ± 0.00	22.00–80.00	37.00 ± 17.20	0.10–0.72	0.50 ± 0.27	0.03–0.11	0.06 ± 0.03
Sta. Ines	0.50–1.00	0.94 ± 0.17	8.00–106.00	47.44 ± 33.56	0.00–1.00	0.19 ± 0.31	0.06–0.15	0.09 ± 0.03
San Martin	0.014–0.017	0.02 ± 0.00	10.00–51.00	27.33 ± 18.38	0.22–0.28	0.25 ± 0.03	0.01–0.51	0.20 ± 0.23
Muhon	0.01–0.017	0.01 ± 0.00	20.40–43.90	37.13 ± 7.19	0.05–0.17	0.09 ± 0.05	0.016–0.094	0.06 ± 0.02
Natumolan	0.01–0.016	0.01 ± 0.00	28.40–38.10	33.06 ± 3.22	0.01–0.07	0.03 ± 0.03	0.02–0.081	0.04 ± 0.02

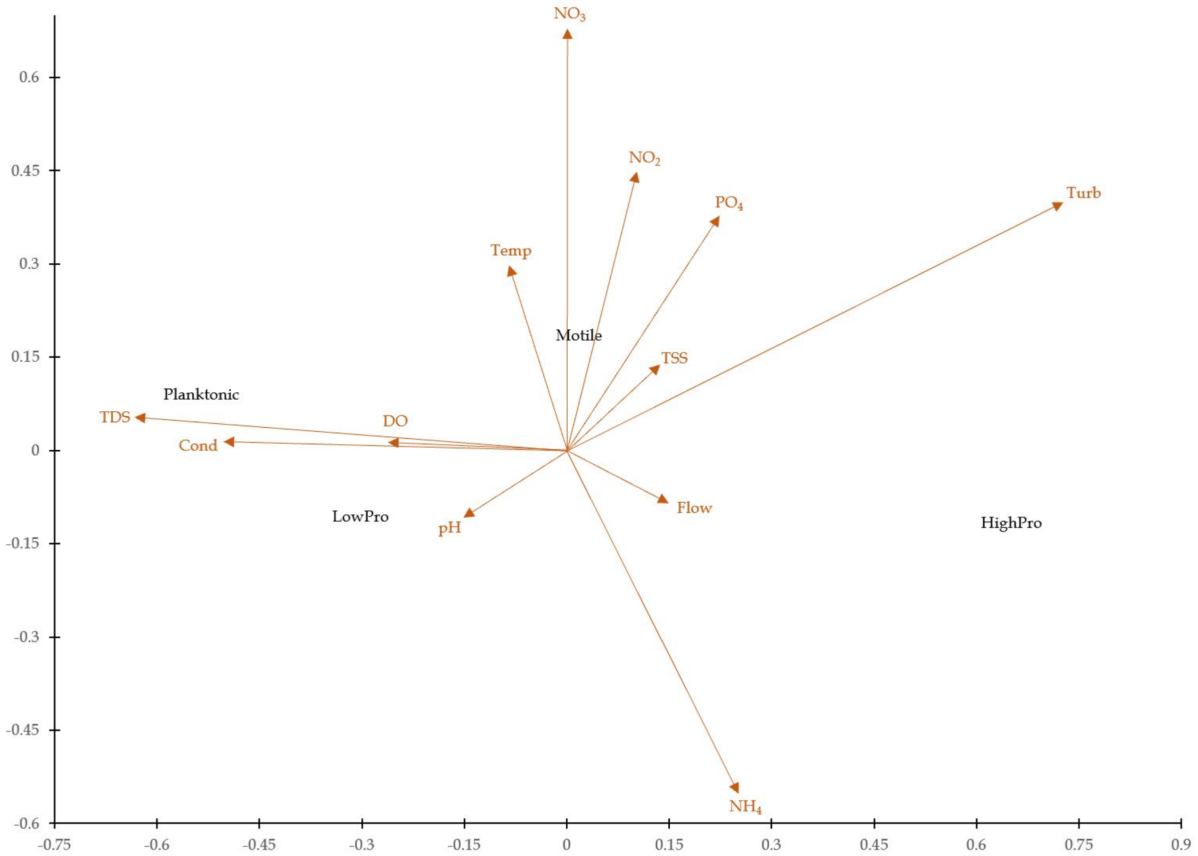

Fig.3. CCA showing the relation of diatom ecological guilds and the environmental variables based on guilds' relative abundances (Axis 1: 84.33%; Axis 2: 13.94%; p = 0.015).

4. Discussion

Navicula (19.24%), *Cocconeis* (16.34%), and *Achnanthidium* (12.78%) were the most abundant diatom genera in the Tagoloan River Basin (Table 2). These three genera were also the most abundant genera in 25 of the 28 sampling sites. *Navicula* was the most abundant in 7 sites (Diklum, Natumolan, Patpat, Sangkanan, San Martin, Sta. Cruz, and Sta. Ines); *Cocconeis* in 12 sites (Capitan Bayong, Dalirig, Impalutao, La Fortuna, Lunokan, Maluko, Omagling, Poblacion (I), Puntian, San Vicente, Silo-o, and Sto. Niño); and *Achnanthidium* in 3 sites (Muhon, Poblacion (II), and Sumalsag) as shown in Table 3. The cells of *Navicula* can be solitary, free living or motile and they were the most abundant in the river basin because they are tolerant across a huge range of pH levels, eutrophication, and conductivities (Taylor and Cocquyt, 2016). *Cocconeis*, on the other hand, is also found across a range of pH and trophic levels; they are also adapted to different substrate (Taylor and Cocquyt, 2016). *Achnanthidium* is usually attached via its mucilage stalk and is typically found in different trophic levels (Taylor and Cocquyt, 2016).

Total suspended solids (0.9749), flow (0.1185), total dissolved solids (0.0839), pH (0.0543), and conductivity (0.0456) were the dominant factors based on the PCA done (Table 4). Among the physicochemical conditions measured, pH, temperature, TSS, nitrate, and phosphate were the factors which had measurements that were above or below the standard value or were out of range based on the water quality guidelines of DENR (Tables 5 to 7).

There is a correlation between the total solids in the rivers and diatoms. The TSS are composed of the organic matter, substrate, and wastes in the water and these are significantly correlated with diatom assemblages (Dickman et al., 2005; Schroeder et al., 2016). The TDS, meanwhile, are comprised of ions, salts, and organic matter and these also relate to diatom communities (Bate et al., 2004; Kivrak and Uygun, 2012; Sudhakar et al., 1994). Both are associated with the pollution level of the river.

The potential of hydrogen (pH) plays a huge factor on diatom cell volume, growth and production rates (Berge et al., 2010; Dutkiewicz et al., 2015; Hervé et al., 2012; Kivrak and Uygun, 2012; Scholz, 2014) and the organisms disfavor acidic environments and flourish at a pH of 6.5-8.5. Acidic conditions change the internal pH of diatoms aside from altering the formation of their frustules (Hervé et al., 2012) The siliceous frustules of diatoms serve as pH buffer (Milligan and Morel, 2002). However, such impact still depends upon the species, given that diatoms have adaptations against acidification (Crawfurd et al., 2011).

Diatoms are also sensitive to flow alterations. Changes in flow modify nutrient concentration flux (Porter et al., 2013). Furthermore, the magnitude and duration of the flow are both important for diatom communities, contributing to their growth (Goldenberg-Vilar et al., 2022). At high flow, the community succession of diatoms is affected by the seasonal flood that may occur and thus, only those diatoms with a particular growth form (i.e. stalked) could thrive (Shibabaw et

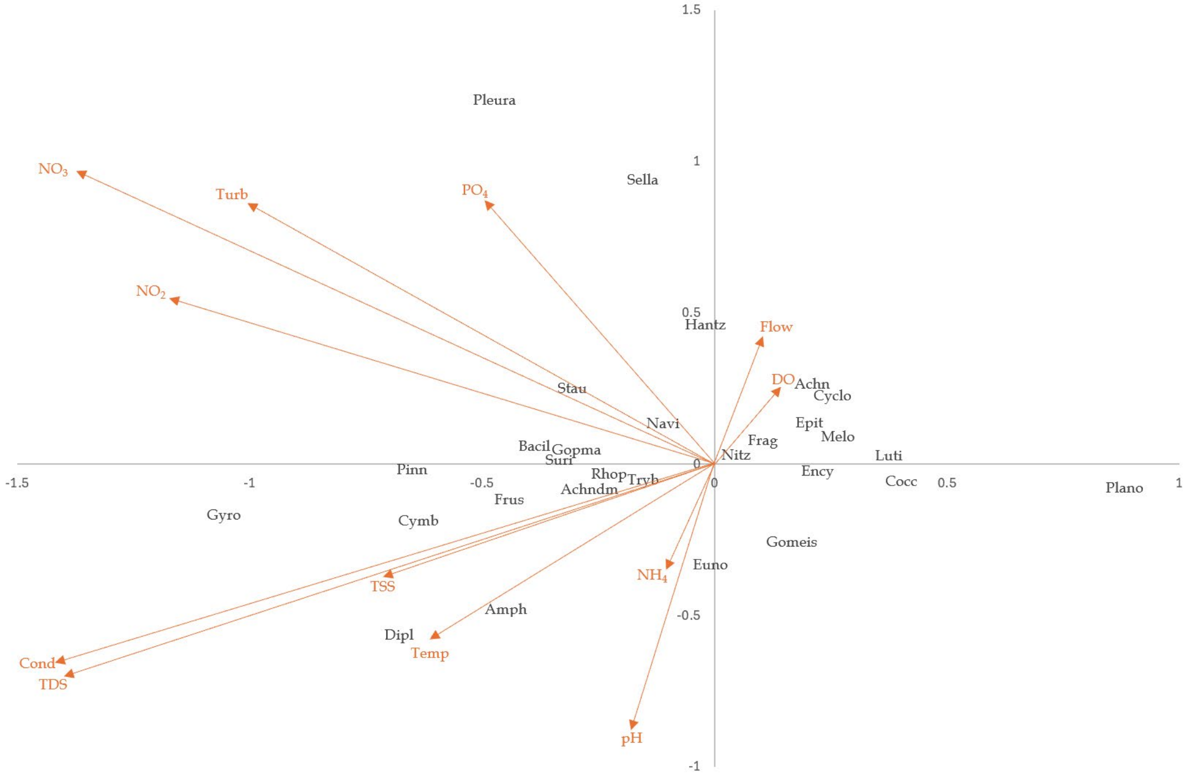

Fig.4. CCA showing the relation of diatom assemblage composition and the environmental variables based on genera abundances (Axis 2: 23.46%; Axis 8: 3.44%; p = 0.044).

al., 2021). However, the abundance and diversity of the algae will increase after some time once the community structure has been established once again.

Electrical conductivity indicates the entrance of an external discharge or pollution into the streams and rivers and is affected by temperature and dissolved solids. Diatom communities are affected by the said factor since they are sensitive to varying degrees of pollution (Bere and Tundisi, 2011; El-karim et al., 2016; Kivrak and Uygun, 2012; Pestryakova et al., 2018; Rioual et al., 2013; Teittinen et al., 2015). The parameter gives insights into the ions that could affect the availability of nutrients which the diatoms need during primary production (Saros and Fritz, 2000). Additionally, the presence of high conductivity and major ions had an impact on the distribution of diatom assemblages (Mangadze et al., 2017).

Diatoms have different responses when it comes to temperature changes; some decrease while other increase when temperature is increased (Cibic et al., 2012). Water temperature affects diatom growth where they favor environments with lower temperature (Javaheri et al., 2015; Necchi-Júnior et al., 2003; Nowrouzi and Valavi, 2011; Schabhüttl et al., 2013; Shatwell et al., 2013; Teittinen et al., 2015; Weckstrom et al., 1997; Xiao et al., 2018) thus hotter climates have a negative correlation with their growths. Diatom assemblages have a strong response to climate warming (Berthon et al., 2014). Temperature directly affects their biochemistry and metabolism (Ingebrigtsen et al., 2016).

Diatoms bloom when there is an increase in nutrient availability. Nutrients are derived from the nitrite (El-karim et al., 2016), nitrate (El-karim et al., 2016; Nowrouzi and Valavi, 2011), phosphates (El-karim et al., 2016; SE. Salomoni et al., 2011; Triest et al., 2001), ammonium (El-karim et al., 2016; S. E. Salomoni et al., 2006; Triest et al., 2001), nitrogen (S. E. Salomoni et al., 2006; SE. Salomoni et al., 2011), and phosphorus (El-karim et al., 2016; Shatwell et al., 2014) dissolved in the rivers and streams. From the said nutrients, nitrate and phosphate were the chemical factors which were included in the WQG by DENR. Nitrate is critical in the growth and survival of diatoms (Allen et al., 2011; Hockin et al., 2012; Kamp et al., 2011) and is one of the most important factors in structuring diatom assemblages (Dalu et al., 2017; Gottschalk and Kahlert, 2012). Nitrogen and phosphorus and their forms are the most important nutrients in the formation of diatom communities (Algarte et al., 2016; Wu et al., 2014). Diatom species respond differently to nutrient enrichment and pollution because of their varying tolerances and thus, the group serves as a useful bioindicator (Bere et al., 2016). They reflect the degree of anthropogenic activities occurring the area (Elias et al., 2015) since most of the sampling sites were agricultural in nature. The values which were above the standards could be associated with the agricultural runoff that the stream receives from the farms near it, leading to eutrophication. Agricultural land-use leads to surface run-off and in the process, allows additional nutrients to flow into the streams (Nhiwatiwa et al., 2017; Zhang et al., 2012). Nutrient enrichment just like that of phosphorus, is considered a precursor to eutrophication and water bodies highly enriched with the said nutrient bears decreased species richness (Jeppesen et al., 2000). Phosphorus not only drives the community composition but it is also a crucial element influencing

Table 7. Relative abundances of diatom ecological guilds in the 28 sampling areas of the Tagoloan River Basin. Values in red indicate the most abundant guild in each sampling site.

Sampling Area	Guild Relative Abundance (%)			
	Low-profile	High-profile	Motile	Planktonic
Kibalabag	50.89	14.19	34.89	0.03
Mat-i	10.31	75.61	14.06	0.03
Dalwangan	33.69	31.17	34.86	0.28
Cawayan	20.17	39.58	39.83	0.42
La Fortuna	51.17	13.06	35.64	0.14
Impalutao	51.47	11.81	36.61	0.11
Sta. Cruz	8.39	52.56	39.06	0.00
Puntian	52.89	8.61	38.08	0.42
Sangkanan	50.17	16.47	33.00	0.36
San Miguel	20.19	27.94	51.83	0.03
Capitan Bayong	52.17	16.36	30.72	0.75
Tangkulan	8.39	61.94	29.67	0.00
Poblacion (I)	41.53	25.67	32.72	0.08
Diklum	21.08	32.64	46.25	0.03
Lunokan	60.44	18.78	20.75	0.03
Sto. Niño	57.06	7.81	33.28	1.86
Dalirig	44.94	16.53	38.53	0.00
San Vicente	48.89	17.08	33.67	0.36
Maluko	69.28	5.42	25.31	0.00
Silo-o	60.44	8.19	31.36	0.00
Omagling	49.14	14.53	36.33	0.00
Poblacion (II)	43.50	8.42	47.97	0.11
Sumalsag	59.22	14.72	26.06	0.00
Patpat	34.19	20.42	45.36	0.03
Sta. Ines	31.94	20.61	47.44	0.00
San Martin	36.47	31.17	32.25	0.11
Muhon	38.42	25.14	35.36	1.08
Natumolan	32.56	24.14	41.97	1.33

how diatoms react to climate change and how sensitive they are to changes in the environment (Berthon et al., 2014). Nitrogen coupled with climate warming due to human-based activities, were found to cause some of the most changes in freshwater systems. Temperature regulates various ecological processes and thus it has a positive relationship with nitrogen concentrations (Marcarelli and Wurtsbaugh, 2006). In addition, higher temperatures also speed up nitrification processes, thereby negatively affecting the pH levels of the environment (Marcarelli and Wurtsbaugh, 2006). Their interaction drives higher biodiversity losses (Porter et al., 2013). In general, diatoms thrive in nutrient-rich environments particularly where phosphorus and nitrogen are high along with pH and conductivity (Algarte et al., 2016; Estadual De Maringá et al., 2015; Winter and Duthie, 2014).

Environmental variables strongly influence the growth and distribution of diatoms in aquatic ecosystems. Total phosphorus, electrical conductivity, nitrate, and pH are the primary drivers of diatom functional groups, with temperature, dissolved oxygen (DO), and organic matter also playing key roles (Marcel et al., 2017), serving as reliable predictors of diatom composition and shedding light on underlying ecological mechanisms (Lange et al., 2016; Riato et al., 2017). This study confirmed such pattern, revealing that pH, temperature, TDS, conductivity, DO, turbidity, TSS, and nutrient concentrations (NO_2^-, NO_3^-, PO_4^{3-}) significantly influenced diatom ecological guilds as shown in Fig. 2.

The positive association of the low-profile guild with DO, pH, and conductivity; and its negative association with nutrients and turbidity align with the results of Passy (2007b), confirming that low-profile diatoms tolerate high disturbance (Fig. 2). Although there was no clear alignment between the low-profile guild and flow (Fig. 2), representatives of the said guild (*Achnanthes*, *Cocconeis*, and *Planothidium*) showed a positive correlation to DO and flow (Fig. 3). Flow alterations impact nutrient availability and transport (Porter et al., 2013), with both magnitude and duration shaping diatom communities (Goldenberg-Vilar et al., 2022). Strong substrate attachment mechanisms allow species such as *Achnanthes* and *Planothidium* to persist in high-flow environments (Passy, 2007b). *Cocconeis* species, highly resilient to environmental disturbances, dominate lotic systems (B-Béres et al., 2014; Stenger-Kovács et al., 2013). DO plays a crucial role in respiration and organic matter (Salomoni et al., 2011; Takarina et al., 2017), supporting higher species richness in well-oxygenated environments (Dalu et al., 2017; Shibabaw et al., 2021; Teittinen et al., 2015). Low-profile diatoms prefer nutrient-poor environments, where limited biofilm formation prevents competitive exclusion (Lange et al., 2011; Passy, 2007b).

Contrary to low-profile diatoms, high-profile species thrive in nutrient-rich, low-flow environments where they form tall, multicellular structures that allow them to utilize important nutrients. High-profile guild members exhibited a strong positive association with turbidity and a negative correlation with flow (Fig. 2), supporting the work of Passy (2007b). Turbidity affects light availability and water quality (Nardelli et al., 2016), indirectly influencing diatom assemblages by limiting chlorophyll-a production (Shibabaw et al., 2021). Increased shading from TDS and TSS favors high-profile diatoms, reducing low-profile guild competition (Leira et al., 2015). Agricultural runoff, a key contributor to turbidity, introduces sediments and nutrients into streams, further benefiting high-profile diatoms (Shibabaw et al., 2021). *Pleurosira*, *Gomphonema*, and *Eunotia* showed strong correlations with NO_2^-, NO_3^-, PO_4^{3-}, and NH_4^+ (Fig. 3), consistent with findings from Sharifinia et al. (2016), Sinco and Metillo (2010), Taylor and Cocquyt (2016), and Van Dam and Mertens (2023). While nutrient tolerance varies among high-profile species (Taylor and Cocquyt, 2016), overall, they favor nutrient enrichment (Passy, 2007b).

Motile diatoms (*Epithemia*, *Hantzschia*, *Luticola*, *Navicula*, *Nitzschia*, *Pinnularia*, *Sellaphora*, *Stauroneis*, and *Surirella*) were positively associated with NO_2^-, NO_3^-, PO_4^{3-}, turbidity, DO, and flow (Fig. 3). Like high-profile diatoms, they prefer nutrient-rich, low-disturbance environments (Passy, 2007b). Fig. 2 confirmed their strong association with NO_2^-, NO_3^-, and PO_4^{3-}, indicating nutrient tolerance. Motile diatoms can actively relocate to optimize environmental conditions, allowing them to persist despite high flow rates. Nutrient supply is crucial in shaping motile guild composition (Larson and Passy, 2012; Stenger-Kovács et al., 2013).

Cyclotella was the sole representative of the planktonic guild, which was expected due to its preference for lentic waters. Its presence in the epilithon may be attributed to extracellular polymeric substances (EPS) or adhesive bacterial and fungal secretions, enabling substrate attachment (Wang et al., 2014). Planktonic diatoms resist sedimentation (Rimet and Bouchez, 2011), utilizing thin frustules and increased surface area for buoyancy and energy efficiency (Marcel et al., 2013). *Cyclotella* thrives in medium-to-high conductivity and high trophic levels (Taylor and Cocquyt, 2016), as indicated in Fig. 2.

The findings reinforce the ecological roles of diatom guilds and their strong associations with environmental parameters, highlighting their potential for biomonitoring in the Tagoloan River Basin as supported by Fig. 3. Low-profile diatoms, which thrive in high-flow, nutrient-poor environments, indicate pristine or less-disturbed sites. Seventeen of the sampling sites (Capitan Bayong, Dalirig, Impalutao, Kibalabag, La Fortuna, Lunokan, Maluko, Muhon, Omagling, Poblacion (I), Puntian, Sangkanan, San Martin, San Vicente, Silo-o, Sto. Niño, and Sumalsag) were mostly composed of low-profile diatoms. High-profile diatoms, on the other hand, signal nutrient enrichment and increased turbidity, often linked to runoff and sedimentation. Three sites (Mat-i, Sta. Cruz, and Tangkulan) were mostly composed of high-profile diatoms. Motile diatoms, correlated with organic pollution and elevated conductivity, suggest pollution stress. These guild-environment relationships confirm that diatom assemblages effectively reflect water quality changes. Eight sites (Cawayan, Dalwangan, Diklum, Natumolan, Patpat, Poblacion (II), San Miguel, and Sta. Ines) were mostly composed of motile diatoms. Though low-profile diatoms were the most abundant in San Martin (36.47%) and Muhon (38.42%), the close percentage of motile diatoms in the said sites (32.25% and 35.36%, respectively) could indicate increased pollution. On the contrary, though motile diatoms were the most abundant in Dalwangan (34.86%) and Cawayan (39.83%), the close percentage of low-profile diatoms in Dalwangan (33.69%) and of high-profile diatoms in Cawayan (39.83%) may indicate less disturbance and enriched nutrients in the said sites, respectively.

5. Conclusions

A functional group-based approach, particularly at the genus level, offers a fast and cost-effective alternative to species-level identification, reducing the need for specialized taxonomic expertise. This is especially valuable in developing tropical Southeast Asian countries like the Philippines, where physicochemical analyses can be costly. By assessing diatom guild composition, researchers and environmental managers can efficiently monitor ecosystem health, track water quality trends, and identify pollution sources, promoting the routine use of diatoms in freshwater assessments across Southeast Asian River basins.

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Conflict of interest

The authors declare no conflicts of interest.

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