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Fitness of Plankton Species on the Physico-Chemical Conditions of Umalag River, Tablon, Cagayan de Oro City, Philippines: A Species Distribution Modeling Approach

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Abstract

Plankton species are found in different environmental conditions due to various requirements for their survival and reproduction. These species have adapted to the rapid changes in their environment that resulted from natural selection. Anthropogenic activities have driven and defined the distribution of species and their interaction with the environment. To understand the species diversity and occurrence of planktons in the Umalag River, Tablon, Cagayan de Oro City, a species distribution model (SDM) approach was used to link the ecological and biogeographical relationship between plankton species distributions and the physico-chemical environmental factors. Five (5) common plankton species were found in the water samples such as *Phormidium sp.*, *Merismopedia sp.*, *Lepocinclis sp.*, *Nostoc sp.*, and *Chlorella sp.* These species are common in freshwater bodies as indicators for enriched organic matters caused by industrial, agricultural, and domestic processes. The planktons have displayed temporal changes in terms of their form, function, and selective advantage due to some traits like short-life histories, rapid changes in composition, response to shifting environmental conditions, and their survival abilities. Results revealed that the community of plankton species in both disturbed and less disturbed areas are very much similar (*SJ*=0.625) with no strong correlation between the occurrence of plankton species and the environmental parameters being analyzed. Rivers are well-mixed environments with limiting nutrients that are equally available to the plankton species. Due to the resistant nature of these plankton species, monitoring and sampling of the freshwater bodies must be done regularly to avoid the occurrence of algal blooms.

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Introduction

Planktons are organisms that can be seen under the microscope and comprise the bottom of the food chains in different aquatic ecosystems. Several researchers have found that planktons are significant indicators of climate change. These organisms are ectothermic, where their body changes according to the temperature of their surroundings so that their physiological processes like nutrient uptake, respiration, reproductive development, and photosynthesis can double with a 10°C temperature rise (Denman *et al.*, 2001). Excessive growth of algal and plants due to increased availability of growth factors such as sunlight, carbon dioxide, and nutrient fertilizers is a distinguishing characteristic of eutrophication. For many years, eutrophication naturally occurs when bodies of the lake age and are filled in with sediment (Rast *et al.*, 1988). However, anthropogenic activities have been found to hasten the development of eutrophication by adding more nutrients and sediments through point and non-point pollutants (Li *et al.*, 2022). Eventually, this will alter the trophic states of the bodies of water for decades. As a consequence, this endangers recreational water bodies, drinking water sources, and aquatic resources.

For the functioning of the ecosystem, the composition of species plays a key role. Several reports have positively shown the effects of biodiversity on the different essential processes in the ecosystem (Otero *et al.*, 2020). On the other hand, this relationship can vary between taxonomic and functional diversity components across all trophic levels. Largely, this mechanism has suggested that plankton communities never reach and maintain equilibrium due to external forces like environmental fluctuations in essential resources and disturbances and other species surrounding them (Mukhopadhyay, 2007). Resources present in the environment are not homogeneously distributed and vary spatially and temporally. Moreover, plankton species can coexist if they are neutrally competitive.

This study aimed to describe the species diversity and occurrence of planktons in the Umalag River, Tablon, Cagayan de Oro City, by using a species distribution model (SDM) approach to build a foundation of the ecological and biogeographical relationship between plankton species distributions and the physico-chemical environmental factors. According to Pearson and Dawson (2003), SDMs are appropriate for predicting potential impacts of probable patterns of anthropogenic activities concerning species distribution. It can describe the presence of species and the environmental factors that influence their growth and survival. Moreover, this modeling approach provided insights into the environmental factors that can influence the patterns of plankton diversity and presence using environmental predictors such as temperature and nutrients. With the influence of climate change, several researchers have reported that temperature and nutrients have a direct effect on the presence and growth of plankton species which can also intensify cyanobacterial blooms. This was established in the study of Gerhard *et al.* (2019) where the variability of temperature interacts with the available nutrients in the physiology and stoichiometry at the community level of plankton species.

Materials and methods

Study area

As shown in Figure 1, the Umalag River (8° 29' 7" N, 124° 43' 31" E) basin lies between the Cagayan and Tagoloan River basins in the North-Central portion of Mindanao Island with an elevation of 8.48528,124.72528 (Lat/Long). Its watershed covers approximately 2,400 hectares of land that extends to the edge of the Bukidnon plateau. The river flows through rugged terrain and deeply incised channels towards Macajalar Bay (DENR-EMB X, 2011). Based on DENR's water classification, the upper stream of the Umalag River is classified as Class A, while the downstream is class C. In the downstream portion of the river, the residential site of Barangay Tablon dominated the area and in the middle stream, some industrial firms which include two (2) food manufacturing companies, an electric generating facility, and a milling industry are located. At the upper stream, there are few scattered residences but the area is predominantly agricultural especially up to the Bukidnon region. Umalag River receives a huge quantity of sewage resulting in large loads of organic pollution which can contribute to the significant growth of microorganisms.

Establishment of Sampling Sites

In a span of approximately two (2) kilometers of the Umalag River, the sampled areas were categorized, as either disturbed or less disturbed. The disturbed areas (Fig. 2) are downstream parts of the river with exposure to several anthropogenic activities like washing clothes, swimming, bathing farm animals, and the presence of houses beside the river. On the other hand, the less disturbed areas (Fig. 3) are upstream parts of the river with less exposure to the said anthropogenic activities. In each sampling area, there were three (3) stations to properly represent the water and plankton samples.

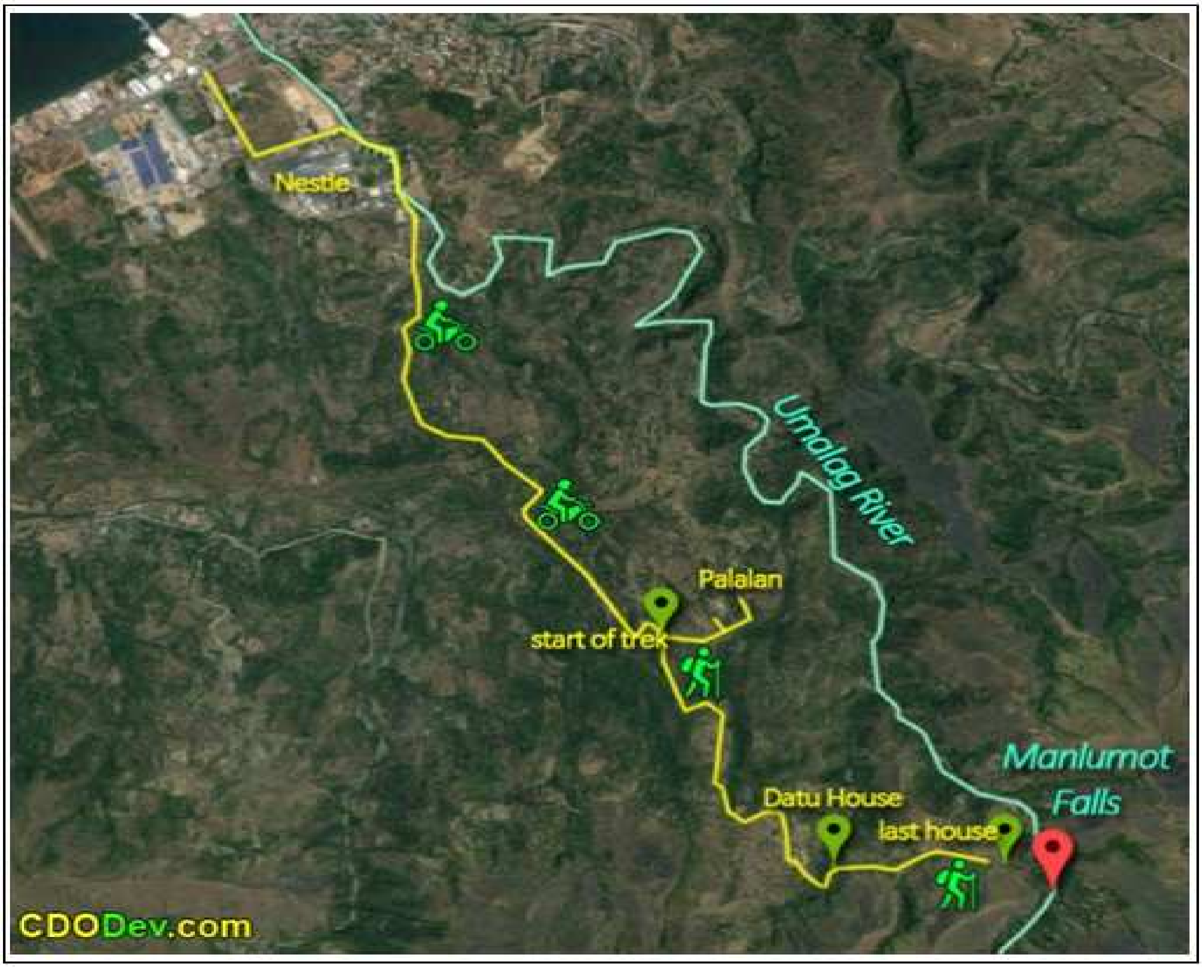

Fig. 1. Study area showing the Umalag River, Tablon, Cagayan de Oro City.

Analysis of the Physico-Chemical Properties of Water Quality

The parameters of water quality were selected based on the associated limiting factors on the growth of plankton. Based on the findings of Hecky and Kilham (1988), these limiting factors are pH, turbidity, temperature, dissolved oxygen (DO), depth of water, nitrates, and phosphates. Water samples were taken from the three (3) stations in the sampling site for the analysis of nitrates and phosphates. The other parameters like pH, turbidity, temperature, dissolved oxygen (DO), and depth of water were measured in situ with the use of scientific gadgets.

Microbiological Parameter for Plankton Collection

In the three (3) stations of the sampling site, the collection of planktons was established using a plankton net. Water samples were preserved with glutaraldehyde shortly after collection in amber-colored bottles and stored in cold (4°C) before sample processing. Observation of planktons was carried out using a light microscope.

Using a graduated cylinder, the volume of each sample was measured. After measuring, each of the samples was transferred back to their respective bottles for sub-sampling. During the subsampling, each bottle was shaken vigorously to obtain 1mL using a dropper. In a depression slide, this process was repeated three times for each of the other bottles or until no other new plankton species was found. Each specimen that was found was photo-documented at 10x magnification of the light microscope. Identification was made possible using various reference guides based on basic algal taxonomy with numerous original illustrations and photographs (Bellinger and Sigee, 2010; Stadtländer, 2013).

Modeling of Plankton Species

To establish an ecological and biogeographical association of plankton species distributions and the physico-chemical conditions of the freshwater samples, this study utilizes the species distribution model approach. This approach can best describe the presence of species and environmental factors that can directly influence their growth and survival in the ecosystem. Also, this model can predict patterns of plankton diversity using various environmental predictors. For all data analysis, PAST (Version 4.03) was put to use for computing and plotting multivariate statistics.

Distribution of Plankton Species

To summarize data on the communities of plankton species, a species-by-sites table was used to describe the information on the two separate sites and the occurrence of plankton species. To compute the index of similarity, the Jaccard index was used to show the proportion of species out of the total number of species that were listed in the two (2) sites, which is common to both sites. The Jaccard index has the following formula:

$$SJ = c\ (A + B - c)$$

Where,

SJ is the similarity index of Jaccard

c is the number of species shared by the two sampling sites

a and b are the number of species unique to each of the sites.

In the result, the similarity index of Jaccard has values ranging from 0 to 1. Values closer to 1.0 indicate that the two (2) sampling sites are similar in terms of the plankton species present in the respective areas. Meanwhile, if the value of both sites is the same, it is considered 1.0, and the two (2) sites are similar.

Canonical Correspondence Analysis (CCA)

In creating the ecological model of the plankton species community sampled in this study, the canonical correspondence analysis (CCA) was used to describe the patterns of species variations that can be explained by the observed environmental variables, temperature, and nutrients. The choice of these environmental variables is based on the results of other related literature that confirms temperature and nutrients are the main driving factors for algal blooms to occur.

The CCA has two (2) axes. The x-axis selects the linear combination of the environmental variables being analyzed to maximize the dispersion of the species scores. Likewise, the y-axis maximizes the dispersion of the species scores by selecting linear combinations of the chosen environmental variables but is subjected to the constraints of being uncorrelated with other CCA axes. Parameters that are near centroids are more likely to realize that state or condition.

Then, the canonical coefficients, as the best weights, were computed for species-environment correlations. To properly interpret the species-environment correlations, each CCA axis is associated with the eigenvalues. The eigenvalues describe how much variation in the plankton species data was explained by the axis and by the environmental variables under study. High eigenvalues fairly describe a strong gradient to the parameter being analyzed.

Results and discussion

Water Quality of Selected Physico-Chemical Parameters

The less disturbed areas in Umalag River, Tablon, Cagayan de Oro City, are classified as Class C which is used for fisheries and aquatic resources, boating, agriculture, irrigation, and livestock watering according to the Water Quality Guidelines and General Effluent Standards of 2016 set by the Department of Environment and Natural Resources.

The average depth of the sampled pool waters in the less disturbed areas is 42.4 inches. Based on previously collected data last 2019 (unpublished), the concentration of *chlorophyll-a*is less than 0.50 mg/L.

Table 1. Water Quality of the Sampled Sites in Umalag River, Tablon, Cagayan de Oro City based on Selected Physico-Chemical Parameters of Water.

Water Parameters	Measured Average Values/Concentrations		Water Quality Guidelines and General Effluent Standards of 2016 (Class C)
	Less Disturbed	Disturbed	
pH	8.28	7.94	6.5-9.0
turbidity	1.78 NTU	5.02 NTU	No Guideline
temperature	24.67°C	24°C	25-31°C
nitrates	10.67 mg/L	8.83 mg/L	7 mg/L
phosphates	6.33 mg/L	2.67 mg/L	0.5 mg/L
dissolved oxygen	8.41 mg/L	6.91 mg/L	5 mg/L

The presence of *chlorophyll-a* concentration in phytoplankton is associated with the optical activity of pigment, appearance, and composition of the algal cells present in the body of water (Wan *et al.*, 2018). The chlorophyll pigment is within the living cells of phytoplankton that can also be found on the surface part of the water. This pigment is important for algal species and is used as an indicator for phytoplankton biomass in the water bodies. According to Ward (1998) in the National State of the Environment Reporting, Estuaries and the Sea, Commonwealth of Australia, low levels of *chlorophyll-a* suggest good water conditions. Based on observation, the sampled waters are still clear without evident formation of green scums.

Meanwhile, the disturbed areas in Umalag River, Tablon, Cagayan de Oro City have an average depth of the sampled running waters in disturbed areas is 33.17 inches. Based on observation, the sampled waters are quite turbid (5.02 NTU) with the formation of green scums in some parts.

As seen in Table 1, some selected parameters are acceptable according to the guidelines set for Class C waters except for the nitrates and phosphates. The average concentrations of nitrates and phosphates have exceeded the stipulated acceptable guidelines. Nitrates and phosphates are significantly found as water pollutants. The most common point and non-point sources of the excessive presence of these nutrients are anthropogenic activities, use of chemical fertilizers regularly, agricultural runoffs, and industrial and domestic waste discharges (Singh, 2013).

Characteristics of Common Plankton Species Found in the Sampled Areas

Five (5) common plankton species were found in the water samples. These are *Phormidium sp.*, *Merismopedia sp.*, *Lepocinclis sp.*, *Nostoc sp.*, and *Chlorella sp* (Fig. 4).

Table 2. Morphological characteristics of the Planktons found in the less disturbed and disturbed areas in Umalag River, Tablon, Cagayan de Oro City.

Species name	Taxonomy	Morphological traits	References
Phormidium sp.	Kingdom Bacteria Subkingdom Negibacteria Phylum Cyanobacteria Class Cyanophyceae Order Nostocales Family Oscillatoriaceae Genus *Phormidium*	filaments usually in the expanded thallus, growing attached to the substrate (secondarily floating in masses); sometimes form tufts or clusters, and are rarely solitary; without any branching; the texture varies (from thin to thick, fine to leathery); slightly waved to loosely, irregularly coiled; sheaths may occur facultatively to almost obligately, depending on environmental conditions; trichomes are cylindrical, sometimes narrowed very near to the ends; mostly long; 5-11(15) μm wide; unconstricted or constricted at cross-walls; conspicuously motile; cells distinctly shorter than wide; or isodiametric to longer than wide; cells lack aerotopes; end cells rounded; or pointed or narrowed; sometimes with a calyptra.	Johansen & Komárek, 2015 Komárek *et al*, 2005
Merismopedia sp.	Kingdom Bacteria Subkingdom Negibacteria Phylum Cyanobacteria Class Cyanophyceae Order Chroococcales Family Chroococcaceae Genus *Merismopedia*	flattened, free-living, platelike (rectangular), more or less rectangular colonies that have one layer of cells, arranged loosely or densely in perpendicular rows and enveloped by fine, colorless, usually indistinct, and marginally diffuse mucilage; colonies are flat or slightly wavy, usually microscopic (except for a few macroscopically visible species), and sometimes composed of subcolonies; cells are spherical or widely oval before the division, pale or bright blue-green, (rarely reddish), and sometimes have visible centro- and chromatoplasm (parietal thylakoids); several have gas vesicles (few or solitary in cell centers); occasionally the cells have slimy envelopes; after division, the cells are hemispherical and (0.4)1.2–6.5(17) μm in diameter.	Komárek, 2003
Lepocinclis sp.	Kingdom Protozoa Phylum Euglenophycota Class Euglenophyceae Order Euglenales Family Euglenaceae Genus *Lepocinclis*	body more or less ovo-cylindrical; rigid with spirally striated pellicle; often with a short posterior spinous projection; stigma sometimes present; discoidal chromatophores (chloroplasts) numerous and marginal; paramylum bodies usually large and ring-shaped, laterally disposed of; without pyrenoids	Kudo, 1966
Nostoc sp.	Kingdom Bacteria Subkingdom Negibacteria Phylum Cyanobacteria Class Cyanophyceae Order Nostocales Family Nostocaceae Genus *Nostoc*	spherical, barrel-shaped, or oval forming unbranched filaments; contain both heterocysts (thick-walled, specialized N-fixing cells) and akinetes (the thick-walled cell which functions as a resting cell); develops colonies with a range of characteristic shapes, sizes, smells, textures, and colors; pigmented and can have a range of colors from dark green to black, yellow-green to red-brown	Borowitzka, 2018
Chlorella sp.	Kingdom Plantae Subkingdom Viridiplantae Infrakingdom Chlorophyta Division Chlorophyta Subdivision Chlorophytina Class Trebouxiophyceae Order Chlorellales Family Oocystaceae Genus *Chlorella*	spherical unicellular eukaryotic green algae that present a thick cell wall (100–200 nm) as its main characteristic	Sydney *et al.*, 2014

The *Phormidium sp.*, *Merismopedia sp.,* and *Nostoc sp.* are cyanobacterial species. Additionally, *Lepocinclis sp.* is a diatom while *Chlorella sp.* is a green alga. All these species are common in freshwater bodies. In addition, the presence of these species may indicate enrichment of organic matters caused by industrial, agricultural, and domestic processes (Conforti, 2017).

The microscopic planktons that were found in the less disturbed and disturbed areas have distinct morphological features depending on their ways of getting food, shelter, and survival strategies (Table 2). Microscopically, the diversity of the plankton is revealed in a particular ecosystem such as freshwater. In general, motility among the planktons is very limited and they mostly depend on currents and the physical environment of their habitat.

Typically, their physical variabilities in open-water habitats satisfy short-life histories, rapid changes in composition, response to shifting environmental conditions, maintenance of diversity, and survival (Reynolds *et al.*, 2013). In addition, planktons exhibit temporal changes in terms of their form, function, and selective advantage.

Table 3. Occurrence of plankton species in the less disturbed and disturbed areas in Umalag River, Tablon, Cagayan de Oro City.

Species Name	Less Disturbed	Disturbed
Phormidium sp.	✓	✓
Merismopedia sp.	✓	
Lepocinclis sp.	✓	✓
Nostoc sp.		✓
Chlorella sp.		✓
Similarity Index of Jaccard (*SJ*)	0.625	0.625

Distribution of Plankton Species

There are five (5) species identified from the freshwater samples obtained in Umalag River, Tablon, Cagayan de Oro City (Table 3). In the less disturbed areas, the planktons found were *Phormidium sp.*, *Merismopedia sp.*, and *Lepocinclis sp.* While in the disturbed areas, the planktons found were *Phormidium sp.*, *Lepocinclis sp.*, *Nostoc sp.*, and *Chlorella sp.* In terms of similarity in the presence and absence of plankton species between two (2) sampling sites, the community of plankton species in both areas are very much similar (*SJ* = 0.625).

Fig. 2. Disturbed areas of Umalag River, Tablon, Cagayan de Oro City.

Fig. 3. Less disturbed areas of Umalag River, Tablon, Cagayan de Oro City.

According to Dodds and Whiles (2010), freshwater sources are well-mixed environments with limiting nutrients that are equally available to the plankton species. At any time, most plankton species have similar needs and compete for the same nutrients.

Thus, in an environment where several plankton species are competing for the same limited resource, the superior competitor will outlast the others. Based on the current findings, the diversity and occurrence of the plankton species present in the two sampling sites depend on predation by zooplankton and viruses, patches of uneven mixing of nutrients, beneficial interactions between species, time of sampling, and difference in the competitive abilities of species.

Fig. 4. Common plankton species commonly found in the less disturbed (A) and disturbed (B) water samples in Umalag River, Tablon, Cagayan de Oro City.

Canonical Correspondence Analysis (CCA)

In building the species distribution modeling, the canonical correspondence analysis (CCA) showed the association between the community of plankton species in each site and their corresponding environmental conditions. As shown in Fig. 5, the plankton species *Merismopedia sp.*, *Phormidium sp.*, and *Lepocinclis sp.* were most likely associated in the less disturbed areas of Umalag River where temperature, nitrate, and phosphate concentrations were high and concentrated compared to the disturbed areas. These species have been reported to be common in eutrophicated waters (Gerhard *et al.*, 2019). Though cyanobacteria species can utilize dinitrogen, a reduction of nitrate loads in the waters has no effect because nitrogen fixation may have been capped and cannot fully reduce the nutrient loads (Molot *et al.*, 2014). This capped fixation can be associated with the limited availability of light, limited bioavailability of other elements like phosphorus, iron, and molybdenum, and movement of water (Paerl and Huisman, 2009). On the other hand, the species *Chlorella sp.* is likely associated with the disturbed areas. *Chlorella* sp. has shown adaptability in industrial wastewaters in the study conducted by Moreno *et al.* (2018). Moreover, this species has been observed to effectively remove nitrogen in the presence of organic sources. The findings of this research have shown positive agreement on the functional traits of the species and the environmental conditions they are found in.

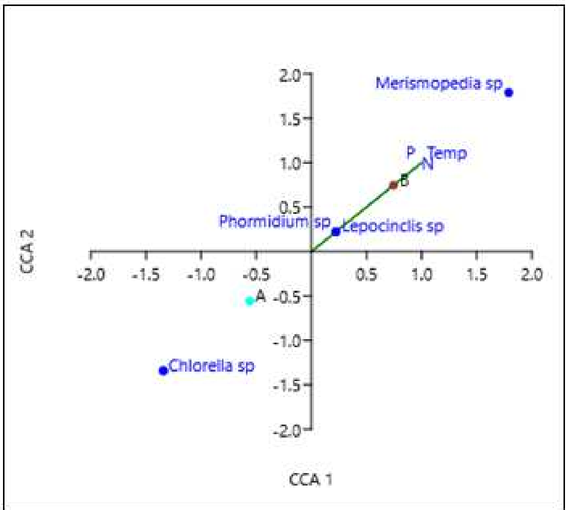

Fig. 5. Canonical Correspondence Analysis (CCA) between the plankton species assemblage and the environmental parameters (temperature and nutrients). *A*: disturbed; *B*: less disturbed.

The eigenvalue in the CCA is low (λ=0.41). Apparently, this expresses a weak correlation between the occurrence of plankton species and the parameters in the environment being analyzed. Given that the two sampled sites are similar (*SJ*=0.625), findings show that the plankton species can be resistant to the changing and mixing environment of the river. As Richardson (2009) reported, planktons are ectothermic and can respond rapidly to changes in temperature by expanding and contracting the ranges that will make them fit and survive in the environment. Moreover, the dispersal mechanism of these species is not dependent on currents and other species but more on physical processes. Thus, the distribution of plankton species and communities can be predicted by timing in their life cycle, component and structure of the environment, and other climate indices that can affect their growth and survival.

Conclusion

There are five (5) common plankton species found in the less disturbed and disturbed areas of Umalag River, Tablon, Cagayan de Oro City. These are *Phormidium sp.*, *Merismopedia sp.*, *Lepocinclis sp.*, *Nostoc sp.*, and *Chlorella sp.* These plankton species are common in freshwater ecosystems and are good indicators of water quality. According to the Water Quality Guidelines and General Effluent Standards of 2016 set by DENR, the levels of nitrates and phosphates exceeded the Class C standards. Based on the results of the water sampling, the less disturbed areas in the river have higher temperatures and elevated nitrates and phosphates compared to the disturbed areas. At the time of sampling, there is an indication of over-enrichment of these nutrients in the sampled freshwater body even if it is known to be less disturbed with no active anthropogenic activities onsite.

The two (2) sampling sites are quite similar in terms of the plankton species that are present. In the species distribution modeling, *Phormidium sp.*, *Merismopedia sp.*, and *Lepocinclis sp.* are most likely associated with the less disturbed areas while *Chlorella sp.* is likely associated with the disturbed areas of the river. However, there is no strong correlation between the occurrence of plankton species and the environmental parameters being analyzed. This can be attributed to the resistant nature of the plankton being ectothermic and ideal beacons of climate change. The role of plankton as a contributor to climate change and as an indicator of change is important in predicting environmental scenarios in the future time. However, an increase in their population in the freshwaters will lead to eutrophication and pose threat to human and animal health. Thus, monitoring and sampling of the freshwater bodies must be done regularly to reduce the occurrence of algal blooms. This, in turn, will maintain the functionality of the ecosystem for the continuing fitness of the organisms as well.

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