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| RESEARCH ARTICLE

Comparison of Phytoplankton Composition and Abundance (River, Estuary dan Coast) as Potential Water Contamination Bio-Indicators in Tallo Watershed Area

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| ABSTRACT

This study aims to compare phytoplankton composition and abundance in the Tallo watershed area, evaluate its ecological factors and water quality, and their correlation to particular types of water contamination. The study was performed from June to August 2021 at three stations in the Tallo watershed, including the river (1), estuary (2), and coast (3). The results suggested that the ecological parameters were still within the tolerable limit for the organisms to live. 4 classes of phytoplankton found in the Tallo watershed included Bacillariophyceae, Cyanophyceae, Dinophyceae, and Chlorophyceae, with a total of 15 genera. No Dinophyceae was found in the river during the high and low tides and there were 9 genera found during the high tide and 10 genera found during the low tide. As many as 3 classes with 12 genera were found in the estuary during the high tide, and 4 classes with 12 genera were found during the low tide. No Chlorophyceae was found on the coast during both the low and high tides. A total of 10 genera were found during the high tide and 9 genera were found during the low tide. Analysis of variance indicated that Phytoplankton Composition there is a difference in phytoplankton abundance in 3 habitats. Phytoplankton abundance on the coast was the highest, followed by the estuary and the river (coast > estuary > river). From the abundance and the composition of phytoplankton in 3 habitats, there was a strong indication of inorganic nitrogen, heavy metal, and microplastic contamination that occurred in the Tallo watershed.

| KEYWORDS

Phytoplankton Abundance, Watershed, Sungai Tallo

| ARTICLE INFORMATION

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1. Introduction

Planktons are small organisms found in water that drift with even weak currents. Plankton consists of animals known as zooplankton and plants known as phytoplankton (Hui et al., 2021; Tuong & Nguyen, 2021). Phytoplankton can convert inorganic substances into organic substances through a photosynthetic process and are important to trophic-level organisms, such as zooplankton and fish, because they are the primary producers in the aquatic food web (A. K. Singh, 2016)

Bakhtiyar et al. (2020) and Acevedo-Trejos et al. (2015) stated that plankton is one of the main components shaping the trophic structures of food webs and plays an important role in the balance of aquatic ecosystems. The pelagic fish population has a strong correlation to chlorophyll-a and plankton abundance. In addition to its role as primary producers, phytoplankton also provides energy for higher trophic level organisms and serves as a direct food source for coral reef dwellers (Gittings et al., 2021).

Phytoplankton also plays a crucial role as a bio-indicator for environmental and water conditions (Afanasyev, 2019). This also covers their role as an indicator in detecting various types of pollutants' contamination, ranging from physical, chemical, and radioactive pollutants to infective microscopic biological substances in waters that potentially degrade the health and life quality of various aquatic species (Manzoor et al., 2021).

Phytoplankton is capable of converting inorganic substances into organic substances (Durham et al., 2019). This ability allows phytoplankton to monitor water conditions. In addition, phytoplankton can respond sensitively to various ecological factors (Barinova et al., 2015), such as low dissolved oxygen levels, high nutrient levels, poor feed quality or abundance, and predation (Casé et al., 2008). The sensitivity of these phytoplankton relies on their transient characteristics (Lewington-Pearce et al., 2019). Many studies have also uncovered how particular classes of phytoplankton can respond to various environmental contamination and even treat the contamination further (Gomaa et al., 2021; Kiran et al., 2016). Patil (2021) also argued that phytoplankton evaluation has become far one of the most widely used approaches in predicting ecosystem quality.

Water pollution is the contamination of bodies of water, such as lakes, rivers, oceans, and groundwater, due to human activities. This pollution may also be caused by industrial, residential, agricultural, household waste, and fishing activities using poison. The spread of organic and inorganic pollutants into coastal water can contribute to the degradation of water quality due to degraded biological functions (Kennicutt, 2017).

Tallo River is a river located in Makassar. In addition to its ecological function, this river is a habitat for various types of aquatic organisms, ranging from large biota to microscopic organisms. The river also supports social functions as it serves as a transportation route for boats and small vessels. Tallo River is also a fishing ground for crab and shellfish commodities. Local inhabitants utilize the river for aquaculture farming of milkfish, shrimp, and seaweed. Residential areas, a steam power plant, the plywood manufacturing industry, aquaculture, and agricultural farming located near the Tallo River have all contributed to intense pollution exposure. This can affect the bio-ecological condition of the water, including phytoplankton. Phytoplankton has a high sensitivity to small changes in bio-ecological parameters, including changes in pollutant concentrations such as heavy metals and other harmful compounds. Furthermore, intensive pollution can cause changes in the phytoplankton's abundance and composition. Such changes can be an indicator in evaluating ecological quality based on the phytoplankton abundance and composition. The emergence of particular species of phytoplankton could also be an indicator of contaminated bodies of water, as indicated in some studies (González-Dávila, 1995; Kapkov et al., 2011; Khatun & Alam, 2019; Radwan et al., 1990).

From the above description, the authors attempted to perform a study that evaluated the ecological condition and water quality of the Tallo watershed by comparing the composition and abundance of phytoplankton in the Tallo watershed and to evaluate ecological conditions. Several habitats around the Tallo watershed area are still productive for fishery and catching certain types of fish and shellfish for consumption. Considering the shellfish consumption among the local communities, it is important to identify the water quality around the Tallo watershed. The identification of phytoplankton abundance and composition from three different habitats of the Tallo watershed can help to indicate different types of water contamination.

2. Materials and Methods

2.1.Study Area.

The study was performed from June to August 2021 at three stations in the Tallo watershed, including the river (Station 1), estuary (Station 2), and the coast (Station 3), see Figure 1.

Figure 1. Tallo watershed area indicating the sampling sites of phytoplankton: Station 1/ river (5º8'30.02.64" S, 119º28'15.74.76" E), Station 2/ estuary (5º06'19.77" S, 119º26'45.92" E); and Station 3/ coast (5º06'40.82" S, 119º27.26.92" E)

2.2.Ecological Parameter Measurement.

Ecological parameter measurements were performed at three stations. Station 1: Tallo River, Makassar; Station 2: Tallo Estuary; Station 3: Coast connected to Tallo River. Temperature, salinity, and pH in this study will be measured in situ or by direct measurement at the research sites or at three different stations during the high and low tides using a thermometer, a refractometer, and a pH meter, respectively.

Flow velocity is measured using a cork tied with a 10-meter piece of raffia string. The cork is placed on the water's surface and stretched to make sure it travels at full velocity, whilst in the 10 m stretch, the travel time is recorded using a stopwatch. Flow velocity measurement was performed during both high and low tides. Water transparency is measured using a Secchi disk. Dissolved organic matter (DOM) is measured to identify its difference during high and low tides. A water sample is collected and filled into containers. The samples were tested in the laboratory of the Brackish Water Aquaculture and Fisheries Center in Maros.

2.3.Plankton Sampling and Collection.

Samples of plankton were collected to measure the abundance by filtering samples from each station using a 40-μm plankton net 10 times in a 10-liter bucket. The sample was stored in 30 ml containers, and 10 drops of Lugol's iodine solution was added. Each sample was labeled in a bottle and will be transferred to the Laboratory of Brackish Water Aquaculture and Fishery Center to identify the plankton species collected from each station.

2.4.Data Analysis.

Plankton abundance was calculated using the following APHA (2005) formula:

$$N = F \times \frac{Ja}{Jb} \times \frac{Vt}{Vs} \times \frac{1}{Vd}$$

Where,

N = plankton abundance
Vd = the volume of filtered water (10 L)
Vt = the volume of filtered sample (30 mL)
Ja = the container area (1000 mm^2)
Jb = the total analyzed field of view area (100 mm^2)
Vs = the total analyzed water volume (3 mL)
F = the total number of biota found.

In analyzing the data, analysis of variance is employed in this study to compare plankton abundance in three stations. A Tukey Honest Significant Difference (HSD) test will be applied if any significant difference is identified.

3. Result and Discussion

3.1.Research Site Description.

Tallo River is a river located in Makassar City that is 10 km long. The Tallo River flows through 3 provinces and cities, including Makassar, Gowa, and Maros. The Tallo Watershed has been developed as a transformational area for fishing or aquaculture farming among the local communities. There are some potential contaminating waste sources along the river, such as factories, a steam power plant, a hospital, and agriculture or aquaculture farming.

3.2.Ecological Parameter.

The results of ecological parameter measurement from each station during low and high tides are presented in the following Table 1.

Table 1. Results of Ecological Parameters Measurement in Each Station

Station	*Tidal Condition*	*Ecological Parameter*					
		Temperature (°C)	*Salinity (‰)*	*pH*	*Flow Velocity (m/s)*	*Water Transparency (m)*	*DOM*
1 (River)	High Tide	28±0.471	8±0	6.6±0.294	0.0604±0.019	77±0	12.75±3.704
	Low Tide	27±0.942	5±0	6.5±0.122	0.0781±0.024	30±21.700	10.5±3.761
2 (Estuary)	High Tide	28±0.471	23±0.94	6.9±0.125	0.1026±0.010	77±23.570	61.67±5.931
	Low Tide	27±0.471	20±0	6.8±0.125	0.1032±0.049	37±2.357	61.36±3.398
3 (Coast)	High Tide	27±0	33±0	7.5±0.09	0.0772±0.049	100±12.247	56.5±5.755
	Low Tide	29±0	30±0	7.7±0	0.1046±0.050	30±21.70	56.75±1.108

The result of ecological parameter measurement indicated that the ecological condition of the Tallo watershed is still within an appropriate range for fisheries. The temperature range from 27oC-29oC during high and low tide in three habitats was still within the optimal range for aquatic organism growth. Normal tropical water temperatures range from 20 to 35°C (Lewis, 2003), while the optimal temperature for aquatic organisms' growth ranges from 25 to 35°C (Islam et al., 2019). For phytoplankton, varying temperatures can change the activity of enzymes in the phytoplankton cells, regulate the physiological metabolism, and ultimately affect photosynthesis and growth (Gao et al., 2019). The temperature increase is often related to the increasing activities of phytoplankton enzymes involved in photosynthesis (Mai et al., 2021). Increasing water temperature also allows phytoplankton to optimize their growth and productivity (El Gammal et al., 2017). Meanwhile, the effect of increasing temperature can indirectly change the hydrological structure of the water column, which can affect the distribution, production, and size of plankton cells (Winder & Sommer, 2012).

The observed salinity level of the river was 5-8 ‰, the estuary was 20-23 ‰, and the coast was 30-33 ‰. Generally, the salinity will show an increasing trend starting from the river-estuary coast (Park et al., 2022). When freshwater influx is low, estuaries can become as salty as nearby coasts. On the contrary, when freshwater influx is high, estuaries can become completely fresh. Even during normal river flow, the salinity in the estuary can vary between high and low tides. Salinity is higher during high tide because seawater flow increases, while salinity tends to be lower during low tide because freshwater influx increases (Havens, 2018). A similar trend is also observed in the present study. Freshwater phytoplankton can only live at a salinity below 8 ‰ (Jackson et al., 1987), while some other species of marine phytoplankton can live at a maximum salinity of 30 ‰ (Brand & Guillard, 1981). A study performed by Larson and Belovsky (2013) also confirmed that salinity is a determining factor for the abundance of phytoplankton because the abundance of phytoplankton species decreases along with the increasing salinity. Nevertheless, marine phytoplankton species are more resistant to high salinity.

The result of the pH measurement was 5–6 for the river, 6–8 for the estuary, and 7-8 for the coast. Such a result was still within the optimal pH level for aquatic organisms. The average pH of marine waters ranges from 7.4 to 8.5 (Ghoniem, 2011), depending on local conditions, while the majority of fresh waters have a normal pH range of 6.5-8.0 (Lerman & Mackenzie, 2005). The photosynthetic process carried out by phytoplankton will perform optimally under a normal pH range. Although every organism may have a different ideal pH range, the majority of aquatic organisms prefer a pH of 6.5–8.0. By exceeding or falling below this range, organisms may become physiologically stressed (Addy et al., 2004). Sofarini (2012) states that an average pH value of 7.44 can support fish life and plankton as part of their diet.

Water transparency presented in Table 1 is similarly within the acceptable limit for aquatic organisms. Water transparency strongly correlates with phytoplankton growth. Higher water transparency levels will increase the phytoplankton growth rate because more light will penetrate the water, stimulating phytoplankton photosynthesis. Conversely, low light intensity inhibits phytoplankton photosynthesis and blooming and triggers competition between phytoplankton species for light (Lewis et al., 2019). Squires and Lesack (2002) also found that the rapid distribution and optimal abundance of phytoplankton in some great lakes can be promoted by nutrient availability and light intensity.

Flow velocity is one of the key regulators of the phytoplankton population (Vidal et al., 2012). Biomass and the spatial distribution of phytoplankton are also highly dependent on current conditions. A study performed by Li et al. (2013) also reported varying abundance and composition of phytoplankton in waters with different velocities of 0.03 m/s, 0.06 m/s, 0.10 m/s, 0.15 m/s, and 0.30 m/s. The study concluded that the waters with fast currents are dominated by green algae (Ankistrodesmus) and diatoms (Cyclotella and Pleurosigma), while the waters with still currents are dominated by other genera such as Scenedesmus, Schroederia, and Melosira. Waters with a current speed of 0.30 m/s also have less dominant phytoplankton groups than those in waters with calmer currents. The study also reported that currents with flow velocities of 0 to 0.10 m/s are at their most optimal level for the distribution and reproduction of phytoplankton. This is in line with the results of flow velocity measurement at the research sites, where all stations had flow velocities in the range of 0–10 m/s.

Dissolved organic matter (DOM) shows little variation among the three habitats, where the river has lower DOM compared to the other two habitats. DOM plays an important role in increasing biomass and phytoplankton abundance in aquatic environments (Kissman et al., 2017). The presence of human activities around the Tallo River, such as dumping organic waste (food waste), will increase dissolved organic matter in the waters. Organic waste thrown into the water will be carried away by the water flow, especially during high tide. This will cause dissolved organic matter to accumulate in the estuaries and beaches. The accumulated DOM will be decomposed by aerobic bacteria, which convert it into nitrites or nitrates that will provide a source of nutrition for phytoplankton. Furthermore, phytoplankton can absorb dissolved organic matter as organic nutrient sources that contain nitrogen, carbon, and phosphorus (Liu et al., 2021).

3.3.Phytoplankton Composition.

The results of identifying the phytoplankton composition based on the classes collected in this study are shown in Figure 2. From the figures, it is evident that the proportion of Bacillariophyceae is higher on the coast compared to the estuary and the river during high and low tides. Conversely, the proportion of Cyanophyceae in the river and estuary is relatively higher than on the coast. Chlorophyceae were only found in the rivers and estuaries, with a higher percentage in the rivers. Dinophyceae were only found on beaches and estuaries, with a higher proportion on the beach during high tide compared to low tide.

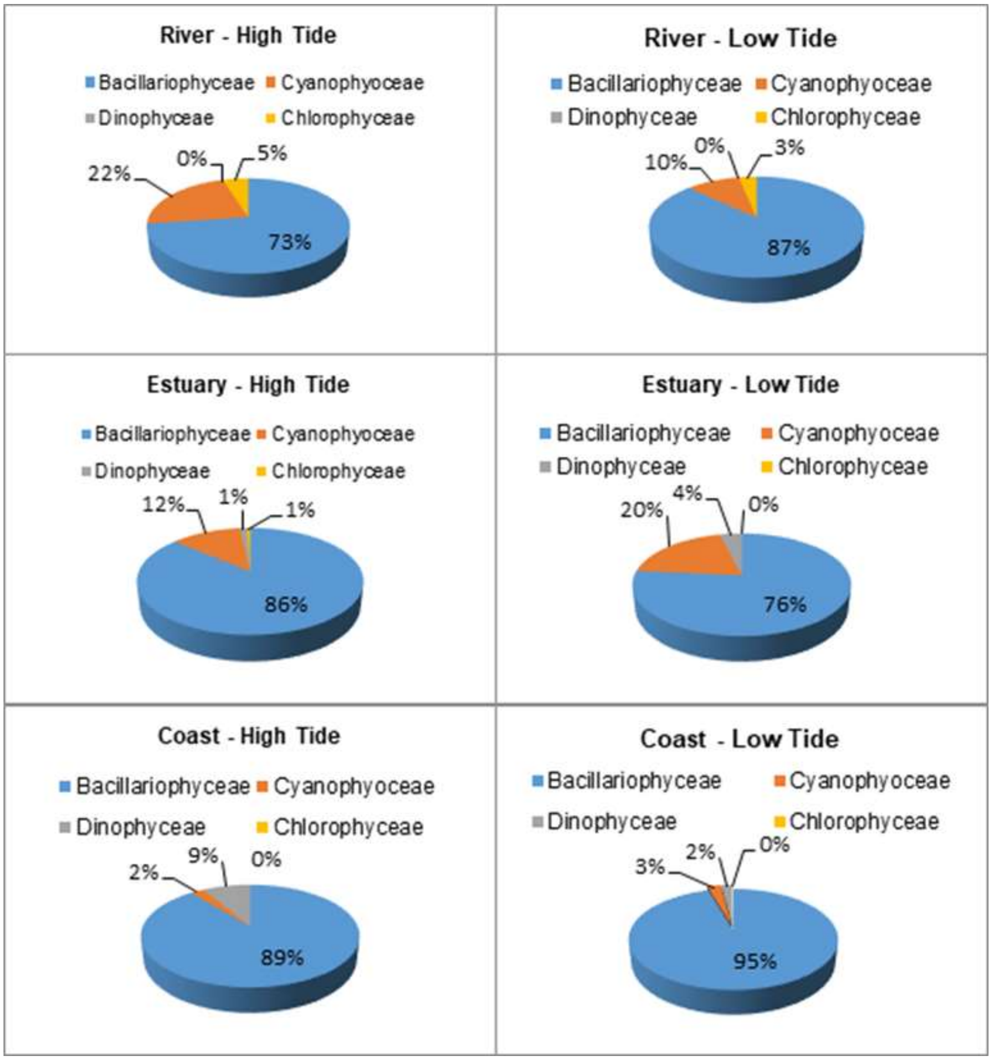

Figure 2. Phytoplankton Composition Based on Class from 3 Different Habitats of Tallo Watershed

Generally, phytoplankton can be classified into 8 divisions, including Cyanophyta, Dinophyta, Bacillariophyta, Chlorophyta, Chrysophyta, Euglenophyta, Haptophyta, and Euglenophyta (Zieger et al., 2018). All of these phytoplankton groups can live in seawater and freshwater except Euglenophyta.

The high concentration of Bacillariophyceae found in each habitat in the Tallo watershed is quite similar to the findings of previous researchers. A study performed by Umar et al. (2009) in Siddo Beach, Barru, found similar dominance of Bacillariophyceae. Harmoko et al. (2019) also studied the phytoplankton community in a waterfall located in Lubuk Linggau and found 4 classes of phytoplankton that were dominated by Bacyllariophyceae. Research conducted by Kostryukova et al. (2018) also found two dominant phytoplankton types, namely Bacillariophyta (42%) and Cyanophyta (39%) in Lake Uvildy, Russia. Nassar et al. (2014) also recorded a total of 145 species from the northwestern part of the Red Sea, Egypt. 76.4% of those species belonged to the Bacillariophyta, and 14.63% belonged to the Donophyta.

The high proportion of Bacillariphyceae in rivers, estuaries, and coasts was most probably promoted by Bacillariphyceae's ability to reproduce rapidly (Brand & Guillard, 1981) and their resistance, which enabled them to adapt to environmental stresses (Fu et al., 2022). The genera found in the Tallo watershed belonging to Bacillariophyceae in 3 habitats include Navicula sp., Pediastrum sp., Skeletonema, Cosconidiscus, Protopredinium, Prorocentrum, Bidduphia, Nitzschia, Arthrospira, Thallasionema, and Chaetoceros.

Another class found in the Tallo watershed was Cyanophyceae, consisting of the Oscillatoria sp. And was collected from the river and the estuary. This is most probably due to the lower salinity since several types of Cyanophyta reproduce more effectively at lower salinity. Some genera of Dinophyceae identified from the estuary and the coast were Dinophysis and Ceratium. This indicates phytoplankton belonging to the Dinophyceae will have optimal growth in waters with higher salinity. One species of Chlorophyceae, Tetrastrum, was found in the samples collected from the estuary and the coast.

3.4.Phytoplankton Abundance.

The data shows the levels of phytoplankton in different areas of the Tallo watershed during high and low tides. In both high and low tides, the highest abundance of phytoplankton was found along the coast, followed by the estuary and the river. This information is presented in Figure 3.

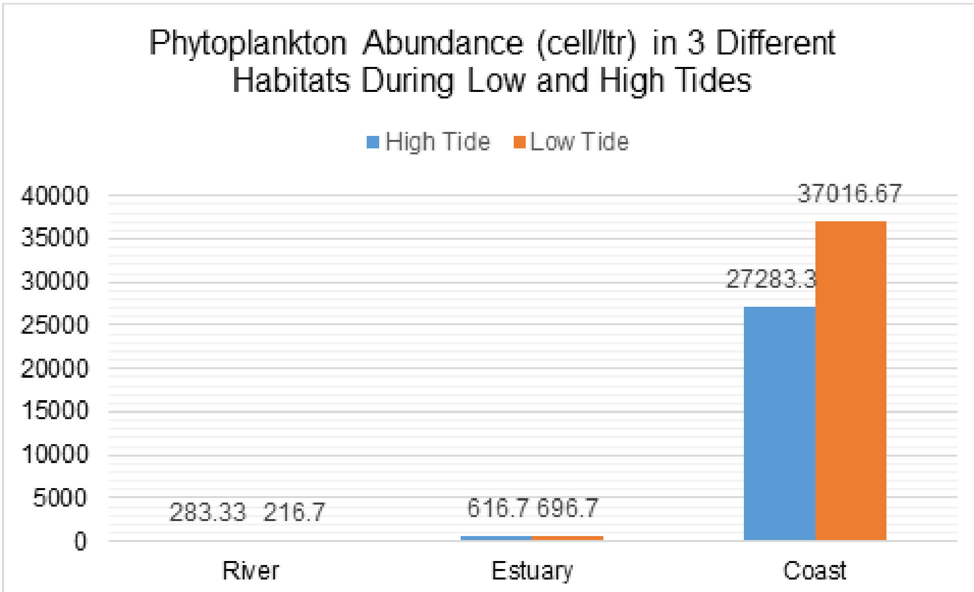

Figure 2. Phytoplankton abundance in each habitat (river, estuary, and coast) in Tallo watershed during high and low tide

The results of the analysis of variance (ANOVA) showed differences in phytoplankton abundance between the three habitats (rivers, estuaries, and beaches). The result of the Tukey test showed the overall trend of phytoplankton in the three habitats: the coast had the highest phytoplankton abundance, followed by the estuary, and the river had the lowest phytoplankton abundance.

Higher phytoplankton abundance on the coast has a strong correlation to the water's transparency. As can be seen from Table 1, the measurement result of coastal water transparency was 100 m, while the transparency of the river only accounted for 77 m. This was in line with the previous studies reporting that phytoplankton abundance strongly correlated with temperature (Lewandowska et al., 2014), phosphate, water transparency (Tian et al., 2021), salinity, and nitrate (Silva et al., 2021). Photosynthesis may occur if light can penetrate the water and reach the algal cells (Churilova et al., 2020).

Higher phytoplankton abundance in the estuary is promoted by better nutrient accumulation supplied from the land and the river and a more tolerable salinity level (Bharathi et al., 2022). Reinl et al. (2022) also added that the growth and survival of phytoplankton are very dependent on macronutrients such as carbon, nitrogen, and phosphorus. However, Parsons and Takahashi (1984) stated that the horizontal distribution of plankton in the sea differs between places due to differences in ecological conditions in various regions such as coastal waters, estuarine waters, and the open ocean.

3.5.Phytoplankton Abundance and Composition as Bio-indicator of Tallo River Contamination.

Generally, the low variation of genera found in the Tallo watershed from 4 classes is most probably promoted by moderate pollution in the Tallo River, as Lestari et al. (2021) confirmed that the estuary waters of the Tallo River are classified as moderately polluted at a pollution index ranging from 7.94 to 9.60. The presence of industries, residential areas, and aquaculture farms around the watershed is considered to be the contributing causes of Tallo River's moderate pollution.

Concerning the phytoplankton's role as a bio-indicator of water quality, the abundant presence of Cyanophyceae (river:10%-22%, estuary: 12-20%, coast: 2-3%), Dinophyceae (estuary: 1-4%, coast 2-9%) and Bacillariophycae (river: 73-87%, estuary: 76-86%, coast 89-95%) is a strong indication of inorganic nitrogen pollution (Nassar et al., 2015). Cyanophycae also have a strong association with higher inorganic nitrogen concentration because they have the capability of N2 fixation (Teichberg et al., 2018). Although inorganic nitrogen pollution may also be caused by fertilizer use from agriculture farming activities around the Tallo watershed, domestic waste from the residential area and industrial area around the Tallo River played a major role in the inorganic nitrogen pollution. Urban, industrial, and septic tank leachate wastewater are the most potential sources of nitrogenous contaminants in the surrounding environments. A study performed by Samawi et al. (2019) found that residential waste and hotel discharges near the Makassar shore are some of the nitrogen pollution sources of wastewater in the Tallo watershed. The ammonia concentrations of nitrogen may have detrimental effects on the local people's health and wellness if no appropriate and sustainable wastewater management is applied before channeling it to the Tallo watershed.

The estuary is predicted to contain higher levels of harmful heavy metal compounds than the coast because the estuary accumulates more heavy metal contents from continuous water flow from the land through the river flow. During the high tide, these contaminants will accumulate and deposit in the estuary, resulting in higher concentrations of heavy metals in both the water and the sediments. On the other hand, pollutants flowing into the coastal water will dissolve and expand to deeper waters, resulting in lower heavy metal contamination. Although a lot of Bacillariophyceae species as the dominant phytoplankton in all observed habitats in the present study can be an indicator of heavy metal contamination in waters because of their phytoremediation property, sensitivity and tolerance against heavy metal concentrations such as Cd, Pb, Cu, Zn (Kiran et al., 2016), the presence of Chlorophycae in the river (3-5%) and estuary (1%) was a stronger indication of lead pollution since Chlorophycae is a prominent bio-indicator of lead (Pb) and copper (Cu) pollution (Szymańska-Walkiewicz et al., 2022).

The existing heavy metal contamination was already confirmed by Rukminasari (2015), who found that of all types of heavy metal (Pb, Cd, Cu, Cr, and Hg) contamination occurring in Tallo River, 3 (Pb, Cu, Cr) of them were considered on a high level of concentration with lead (Pb) reaching on the highest concentration of all. Similarly, Rumoey et al. (2022) also reported and identified the presence of Cr and Pb concentrations from Tallo River (Pb = 0.11 mg/L), estuary (Cr = 0.12 mg/L, Pb = 0.13 mg/L), and coast (Cr = 0.11 mg/L). High Pb concentration identified only in the Tallo River and estuary was most probably promoted by agricultural farming activities around the river and estuary, which involved the use of inorganic fertilizer. A similar trend is also observed in a study by Charkhabi et al. (2005). This result is parallel with the findings in the present study, where Chlorophycae as Pb and Cu contamination bio-indicators were only present in the river and estuary.

The release of heavy metals into water bodies can result in extremely high levels of toxicity that can impair organ development, trigger cancer, damage the nervous system, and ultimately lead to death. The health of the entire aquatic environment, as well as human health, is negatively affected by heavy metal poisoning. Due to the danger posed by bioaccumulation and biomagnification in the food chain, heavy metals can affect the physiological and biochemical characteristics of aquatic animals (Kobielska et al., 2018).

Besides its role as a bio-indicator of inorganic nitrogen pollution, Cyanophyceae (river:10%-22%, estuary: 12-20%, coast: 2-3%) were also a positive bio-indicator for micro-plastic accumulation in the waters. The danger of microplastics to both humans and aquatic species has also been discussed in many studies. Bhuyan (2022) stated that if fish are exposed to microplastics, they will experience neurotoxicity, slowed growth, and deviant behavior. High concentrations of microplastics are reported to generally cause changes in phytoplankton communities, especially increasing the abundance of Cyanophyceae (Hitchcock, 2022). Cyanophyceae are photosynthetic bacteria that often colonize microplastics floating in seawater and fresh water. The results of intensive research from several water and sediment samples in the Tallo River confirmed that this area was contaminated with microplastics (Wicaksono et al., (2021). The study also emphasized that most microplastic concentrations are centered in the Tallo freshwater area due to domestic, industry, wastewater treatment plants, and agrosystems. This is in line with the Cyanophyceae abundance in the present study, where the Cyanophycae community reached the most abundant population in the river (10-22%), followed by the estuary (12 -20%) and the coast (2-23%). The strong correlation of Cyanophyceae to microplastics was not only because of Cyanophyceae sensitivity responding to microplastic concentration, but Cyanophyceae could further serve as a bioremediation actor in polluted waters by microplastics. Cyanophycae can attach the contaminants on the surface of their cells and perform an active or passive transfer of the microplastic contaminants into the cell while continuing to uptake plastic particles (Barone et al., 2020).

4. Conclusion

Based on the results obtained in this study, it can be concluded that 4 classes of phytoplankton were found in the Tallo River, including Cyanophyceae, Dinophyceae, and Chlorophyceae, consisting of a total of 15 genera. No Dinophyceae was found in the river at high or low tide. There were 9 genera during the high tide and 10 genera during the low tide found in the river. From the estuary, 3 classes consisting of 12 genera were found at high tide, and 4 classes consisting of 12 genera were found at low tide. No Chlorophyceae were identified from the coast at low and high tide, but there were 10 genera identified during the high tide and 9 genera during the low tide. ANOVA results indicated that there was a difference in the phytoplankton abundance in the river, estuary, and coast. The phytoplankton abundance on the coast was the highest, followed by the estuary and the river (coast > estuary > river). From the abundance and the composition of phytoplankton in 3 habitats, there was a strong indication of inorganic nitrogen, heavy metal, and microplastic contamination occurring in the Tallo watershed.

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