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Correlation Between the Phytoplankton Distribution with the Oceanographic Parameters of the Deep-Sea Surface of Sangihe-Talaud, North Sulawesi, Indonesia

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Abstract. Phytoplankton is the primary producer and plays an important role in the food chain process, especially in the oceans. This study aims to describe the phytoplankton distribution and correlations with oceanographic parameters in the deep-sea surface, Sangihe-Talaud, North Sulawesi. Research methodologies include; oceanographic data collection (salinity, temperature, dissolved oxygen, and density), field methods, and phytoplankton samples processing. Data analysis includes abundance, diversity and domination index, PCA analysis, and Similarity index. The results showed that the phytoplankton composition in the sea surface layer of the Sangihe-Talaud waters has three classes: Bacillariophyceae and 86% with ten genera i.e., *Chaetoceros*, *Coscinodiscus*, *Dactyliosolen*, *Eucampia*, *Guinardia*, *Hemiaulus*, *Leptocylindrus*, *Pleurosigma*, *Rhizosolenia*, and *Skeletonema*. The class of *Dinophyceae* 8%, as many as 17 genera, i.e., *Actiniscus*, *Amphisolenia*, *Ceratium*, *Ceratocorys*, *Gambierdiscus*, *Gonyaulax*, *Gymnodinium*, *Heterodinium*, *Mesoporos*, *Noctiluca*, *Ornithocercus*, *Oxyphysis*, *Podolampas*, *Prorocentrum*, *Protoperdinium*, *Pyrocystis*, and *Pyrophacus*. The class of *Cyanophyceae* 6% and found only one genus *Trichodesmium*. Phytoplankton abundance was calculated as 65.63 to 1,071.88 cells L⁻¹, with an average of 419.03 cells L⁻¹. The distribution is exhibited that the higher abundance in the southern part near the mainland of the Sulawesi and Maluku channels compared to the northern part, which is directly connected with the Pacific Ocean. The diversity and dominance index of phytoplankton are categorized as generally moderate and no species domination. The correlation between oceanographic parameters with abundance and diversity of phytoplankton is characterized by the identifiers using salinity, density, and temperature; and indicated a strong similarity index.

1. Introduction

Phytoplankton has an important role as a primary producer in the waters' food chain, especially in oceanic or deep-sea waters. Like an oasis in the desert, it is irreplaceable and crucial in the next food chain [1] and also a water quality indicator [2]. The phytoplankton distribution is strongly influenced by the oceanography parameters such as current, temperature, salinity, pH, dissolved oxygen, density [3-7].



Phytoplankton's existence in the Sangihe-Talaud waters, North Sulawesi, is fascinating to be studied because this area is part of Indonesian Throughflow (ITF). These waters are connected directly to the Pacific Ocean. The water masses from the Pacific Ocean will directly affect the oceanographic parameter dynamics, and it is also influenced by the distribution of phytoplankton abundance and diversity. According to a report by [8], the water masses transport from the Pacific Ocean into the Maluku Channel is around $14 \times 10^6 \text{ m}^3 \cdot \text{s}^{-1}$.

Also, the Sangihe-Talaud waters are a seamount volcanic region, which is highly fertile and the spawning ground for the deep-sea biota larval. The seamount volcanoes existed, such as Banua Wahu seamount with a peak only 5 meters under the sea level, Kawio Barat seamount with a depth of 1800 meters, and Submarine 1922 seamount with a depth of 5000 m [9, 10]. Seamount volcanic activity will lead to nutrient-rich and warmer water temperatures. This is reported to be a very suitable environment for deep-sea biota growth in the larval phase and phytoplankton as the primary food source [11].

The characteristics of the Sangihe-Talaud waters are unique, and it is interesting to study the distribution of phytoplankton in the upper layer surface. This information is needed for further deep-sea studies.

2. Material and Methods

2.1 Sampling area

The sampling area is located in the Indonesian Throughflow (ITF) entry passages. The mouth of water masses flow from the Pacific Ocean into the Indian Ocean, which has a depth of more than 4000 m. Besides, the study area is a spawning ground for marine biota because there are sources of warm water from volcanoes seamount activity, such as; the Banua Wuhu seamount, the West Kawio seamount, and the Submarine seamount in 1922 [9, 10].

This research was conducted during the Widya Nusantara Expedition (EWIN) on October 5-24, 2018 using the R/V Baruna Jaya 8, Research Center for Oceanography, Indonesian Institute of Sciences (RCO-LIPI). The sampling site was located around the Sangihe-Talaud Islands and Miangas Island waters, with 33 stations, where the distance between stations is around 30-50 miles. The station was started from Bitung waters towards the Maluku channel, crossed the Miangas Island, and returned to Bitung via the eastern side (Figure 1). Phytoplankton samples were collected at surface waters (< 5 m) during the day and night periods.

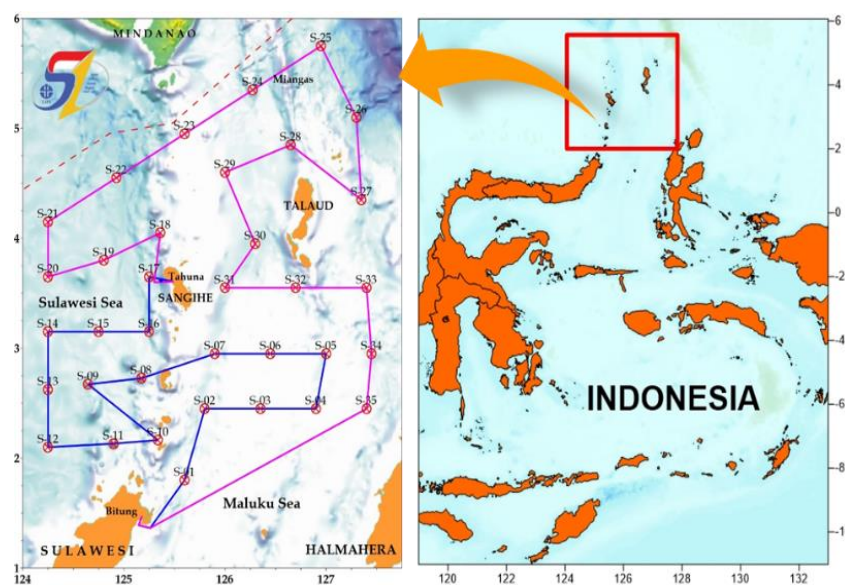


Figure 1. Map of phytoplankton sampling of the Sangihe-Talaud surface waters

2.2 Field methods and samples processing

Oceanographic parameters data were observed at 33 stations comprised of salinity, temperature, dissolved oxygen, and density. Those parameters were measured using Conductivity Temperature Depth (CTD) SBE 911 [12]. The surface water to 5 m depth data is analyzed and displayed using Surfer 9 software.

Phytoplankton samples were collected in the surface layer <5 m using a 20 µm plankton net. Samples were obtained by filtering 80 L of water using barrels pulled from the vessel, and the final filtered volume was 250 ml, which was then preserved with 4% Lugol solution. Phytoplankton genera were observed under a light microscope and identified by references [12, 13].

2.3 Data analysis

2.3.1 *Phytoplankton abundance analysis.* Phytoplankton abundant, N is calculated in cells L^{-1} , following [13] as;

$$N = \frac{n \times v1}{v0} \times 1000 \quad (1)$$

Here, ni is a cell found phytoplankton in the water Sedgwick rafter of counting cell, $V0$ is a volume of filtered water in liters, and $V1$ is a volume of filtered water in ml.

2.3.2 Phytoplankton diversity

Phytoplankton diversity is analyzed using the Shannon-Wiener index (H'), [14], which is domination species analyzed by Simpson Index (C) [15], with formula as;

- $H' = -\sum_{i=1}^s \left(\frac{ni}{N}\right) \left(\ln \ln \frac{ni}{N}\right)$ (2)

- $C = -\sum_{i=1}^s \left[\frac{ni}{N}\right]^2$ (3)

Here, ni is the total of cell species i , N is a total of cell per station.

2.3.3 *Principal components analysis (PCA).* PCA is used to inspect the correlation between the oceanography parameters (salinity, temperature, oxygen, and density) with the phytoplankton abundance and diversity. This analysis determined the identifier parameters to the phytoplankton abundance and diversity for the whole observation stations, which is calculated using the XLSAT 2020 software.

3. Results

3.1 The oceanography parameters of surface waters

Measurement of oceanographic parameters in the surface layer of the Sangihe-Talaud waters has been carried out, which includes salinity, temperature, dissolved oxygen, and density (Figure 2). The salinity range was found between 33.54 to 34.31 PSU or an average of 34.13 PSU. The salinity distribution is shown to be highest around Sangihe Island and slightly lower in the northeastern part of Talaud Islands. This is thought to be influenced by land temperature and seamount activity.

The temperature was found between 28.64 to 30.24 °C with an average value of 29.57 °C. The temperature is more evenly distributed, which was slightly higher in the western and southern parts of the Sangihe Island, where it is located on the Banua Wahu and Submarine 1922 seamount volcanos. However, it declined near the mainland of Sulawesi.

Dissolved oxygen was found between 6.18 to 6.47 mg l⁻¹ with an average value of 6.36 mg l⁻¹. The dissolved oxygen was high in the southern part compared to the northern part. This is considered to be influenced by mainland bathymetry, where there is a strong mixing water mass.

The density was found between 20.85 to 21.50 kg m⁻³ with an average value of 21.22 kg m⁻³. The density pattern is more uniform, except in the north-eastern part where it was found lower. This is thought to be influenced by the Pacific Ocean due to directly connected to the open waters.

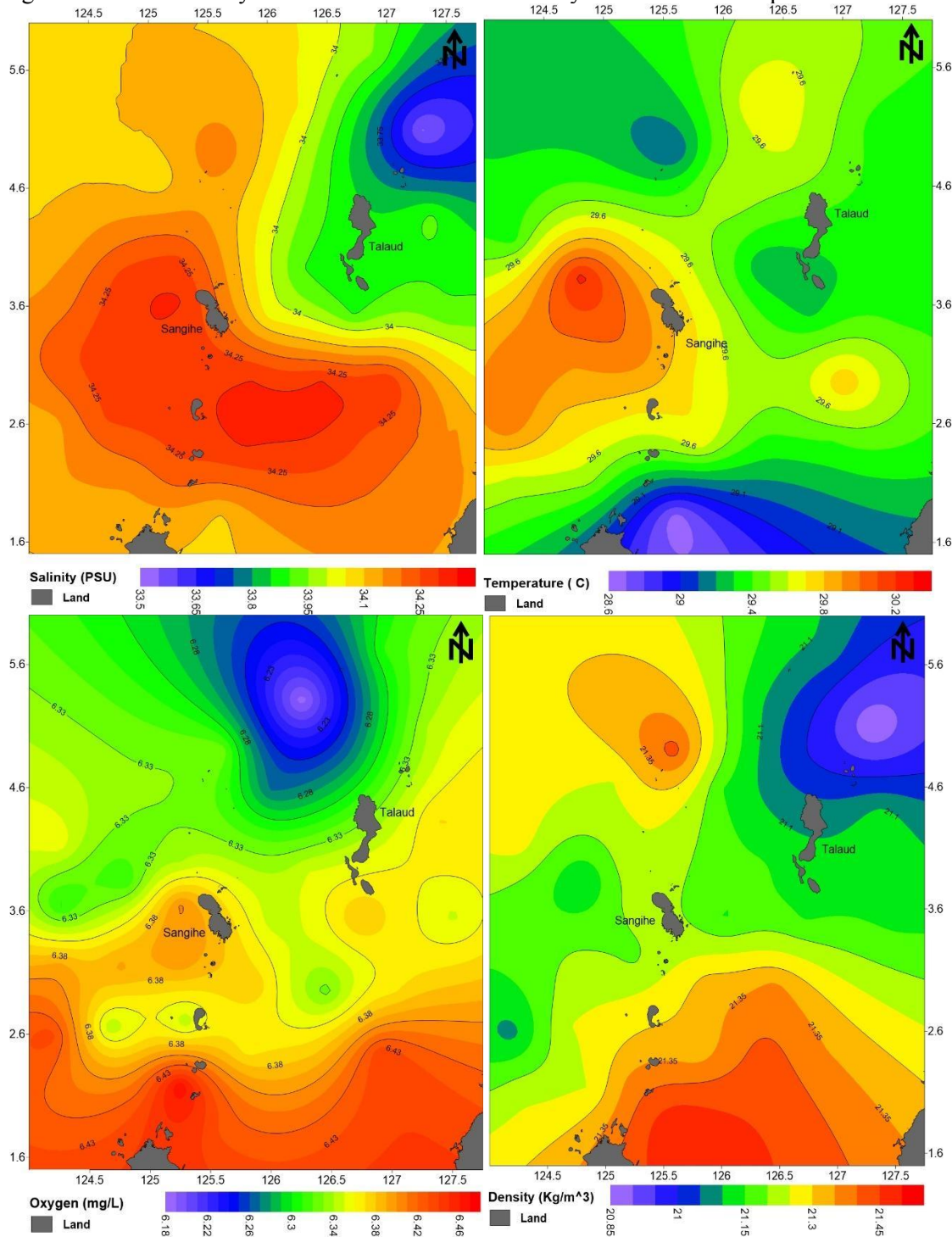


Figure 2. Oceanography parameters of the Sangihe-Talaud surface waters

3.2 Phytoplankton composition

Phytoplankton composition is grouped into three classes: *Bacillariophyceae* is around 86%, *Dinophyceae* 8%, and *Cyanophyceae* 6%. The *Bacillariophyceae* has the highest abundance, ten times more than the *Dinophyceae* and 14 times more than the *Cyanophyceae* (Figure 3).

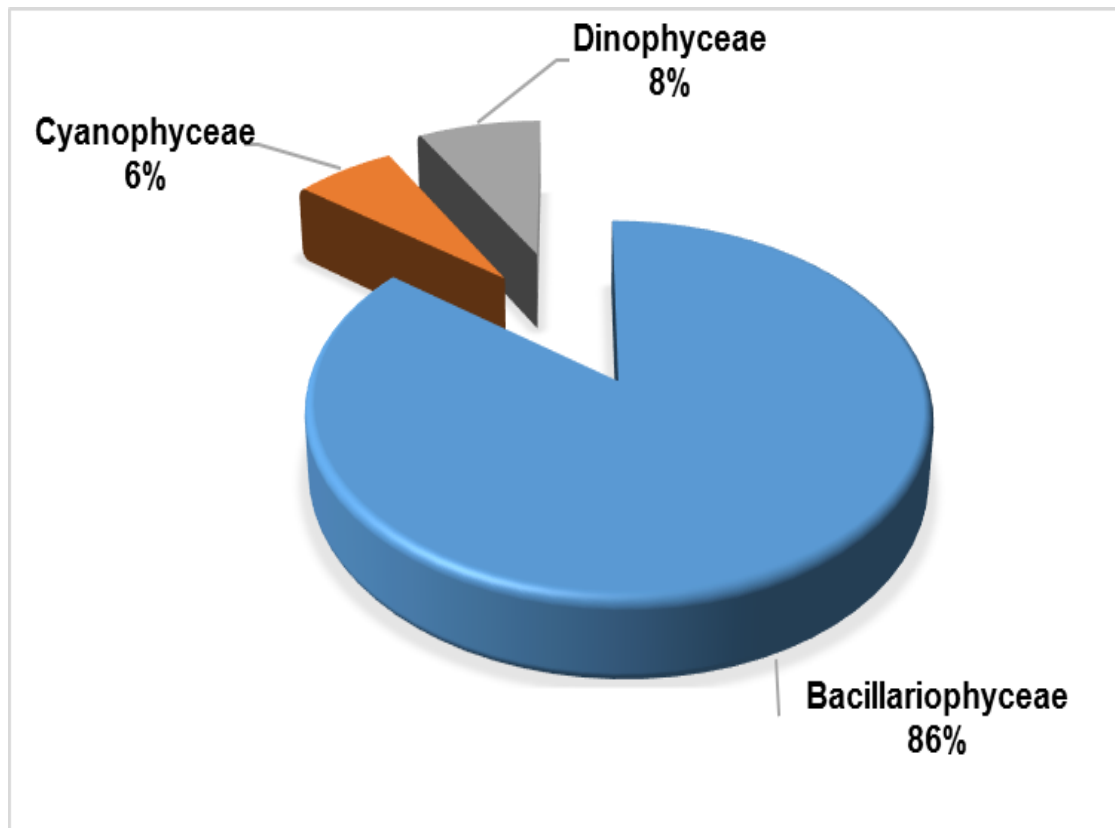


Figure 3. Phytoplankton composition of the Sangihe-Talaud surface waters

Based on Figure 3, *Bacillariophyceae* class identified ten genera, namely *Chaetoceros*, *Coscinodiscus*, *Dactyliosolen*, *Eucampia*, *Guinardia*, *Hemiaulus*, *Leptocylindrus*, *Pleurosigma*, *Rhizosolenia*, and *Skeletonema*. These genera are dominated by *Leptocylindrus* and *Guinardia*. Both were found at each observation station, where the highest was at station 12 (for *Leptocylindrus* 559 cells L⁻¹) and station 3 (*Guinardia* of 484 cells L⁻¹).

The class of *Dinophyceae* identified 17 genera, namely *Actiniscus*, *Amphisolenia*, *Ceratium*, *Ceratocorys*, *Gambierdiscus*, *Gonyaulax*, *Gymnodinium*, *Heterodinium*, *Mesoporos*, *Noctiluca*, *Ornithocercus*, *Oxyphysis*, *Podolampas*, *Prorocentrum*, *Protooperidinium*, *Pyrocystis*, and *Pyrophacus*. This class was shown significantly lower than the previous class, but *Ceratium* and *Mesoporos* were found at each observation station. Both have the highest abundance of 22 cells L⁻¹ (at stations 23 and 25 for *Ceratium*), and 109 cells L⁻¹ (at station 4 for *Mesoporos*). For the *Cyanophyceae* class, we identified only one genus, namely *Tricodesmium*, which was found of a low total of 122 cells L⁻¹ and was also only found in the last nine stations samples (stations 24-33). (Figure 4).

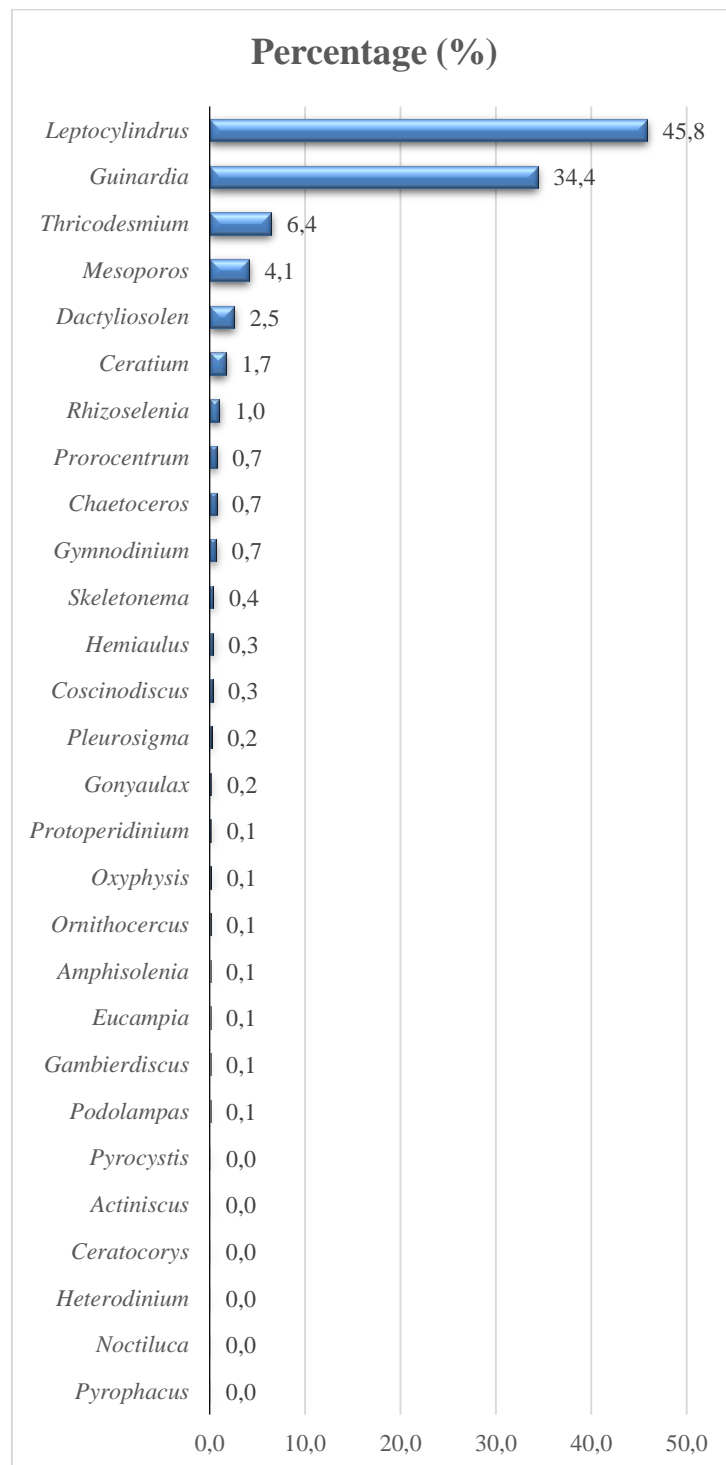


Figure 4. Phytoplankton species percentage of the Sangihe-Talud surface waters

3.3 Distribution of phytoplankton species

The distribution of phytoplankton abundance is shown uneven; where it is high in the southern part compared to the northern with lower quantity (Figure 5). The whole phytoplankton abundance was found around 65.63-1071.88 cells L⁻¹, with an average value of 419.03 cells L⁻¹. This total value was low, it is likely due to lack of nutrients in the waters as it is located in the open and deep sea.

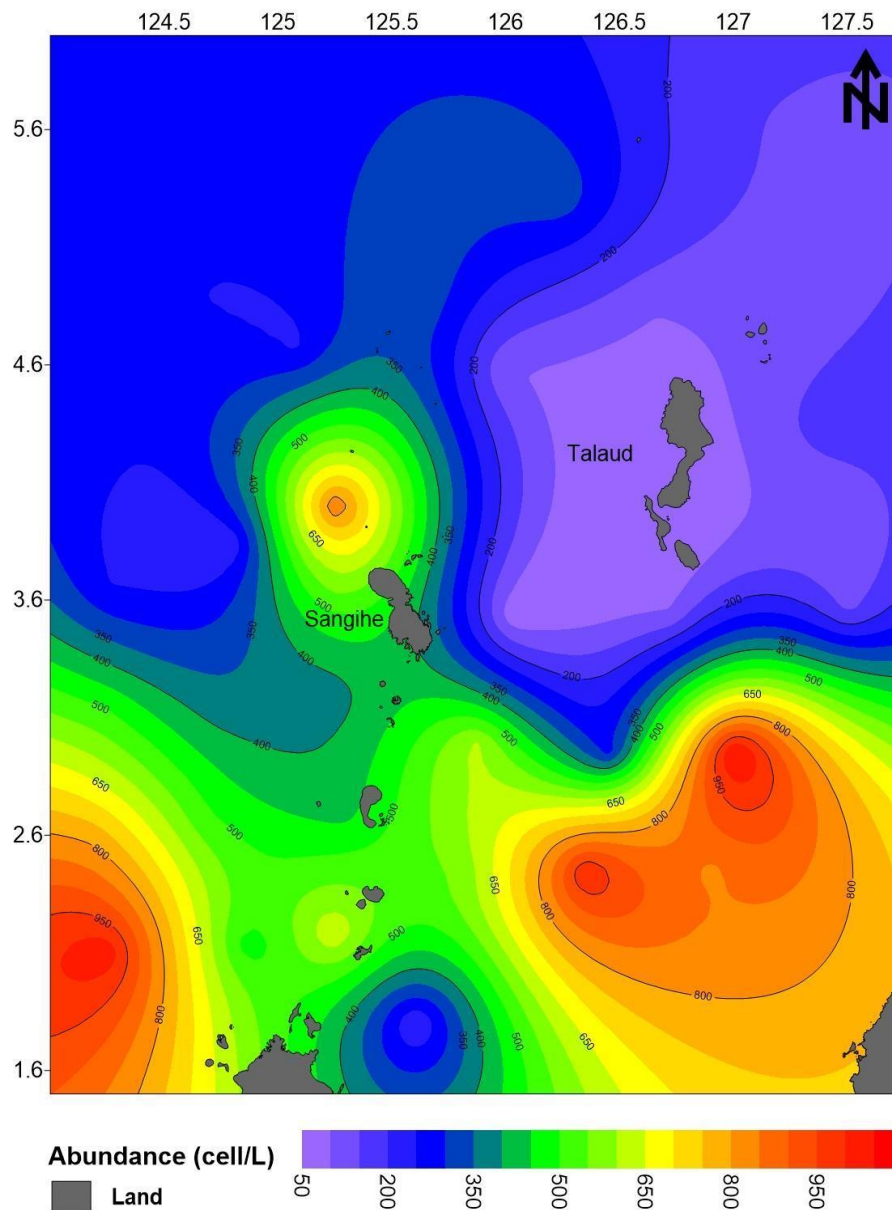


Figure 5. Distribution of phytoplankton genera of the Sangihe-Talau surface waters

As shown in Figure 5, phytoplankton's distribution is higher in the southern part of the Sangihe Islands, especially in the Maluku Channel and the Sulawesi Sea. This area is likely to contain high nutrient due to being closer to the mainland and seamount volcanic activity. The nutrient content is needed for phytoplankton growths. The northern side is featured by low phytoplankton distribution; this may be the impact of nutrients lack caused directly connected to the Pacific Ocean.

The phytoplankton diversity index, in general, it has a medium category ($H' = 1.0$ to 2.8), except for three stations, i.e. 7, 8, and 13 where low category ($H' < 1$) (Figure 6) were observed. The dominance index value indicated that all waters were in a low category ($C < 0.5$), where no species dominates. Both indices concluded that the Sangihe-Talau surface waters were in good condition and there was no pressure on the phytoplankton growths.

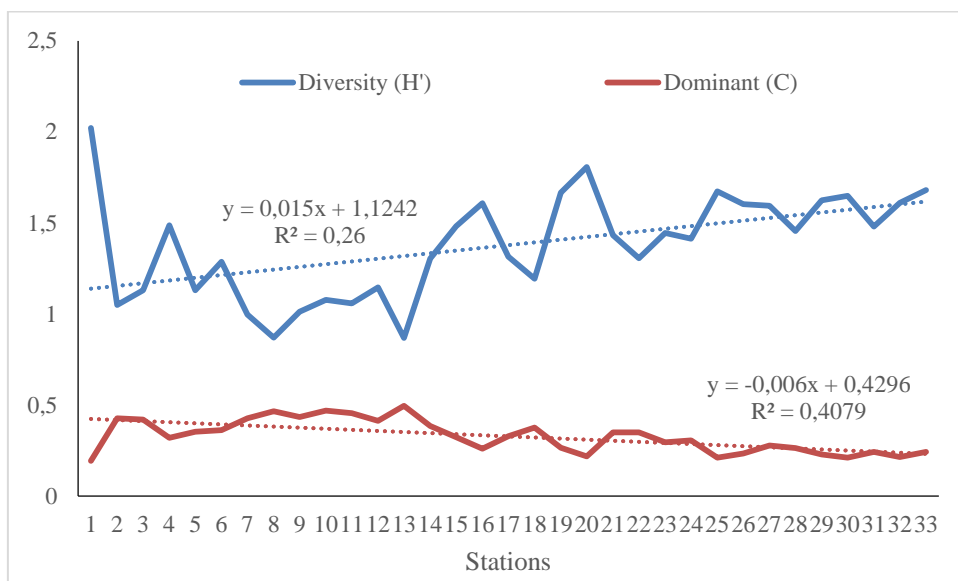


Figure 6. Phytoplankton diversity of the Sangihe-Talau surface waters

3.4 Correlation between oceanography parameters with phytoplankton abundance and diversity

Based on the principal component analysis (PCA), cumulative Eigenvalues were 72.9%, and the variable minimum of 0.42 squared cosine value illustrated that there were three groups of data with each identifier. Two groups were in axes F1, and the other was in axed F2 (Figure 7A).

The description of the three groups of PCA is as follows. The first group includes stations 2, 3, 5, 7, 8, 9, 10, 12, 13, 17, and 18, and the identifiers are the salinity, density, and phytoplankton abundance. Salinity at these stations was 34.1 to 34.31 PSU, with a total of phytoplankton abundance of about 50.9%. The density was around 21.08 to 21.41 kg m⁻³. The second group involves stations 25-33 with the identifiers of diversity index in the medium category (H'=1.46 to 1.68). This group is dominated by the *Guinardia* and *Leptocylindrus* (for *Bacillariophyceae* class), *Ceratium* and *Mesoporos* (for *Dinophyceae* class), and *Thricodesmium* (for *Cyanophyceae* class). The third group includes station 19, the identifier is the temperature, with a value of 30.24 °C. This condition is still good for phytoplankton growth in the tropical regions.

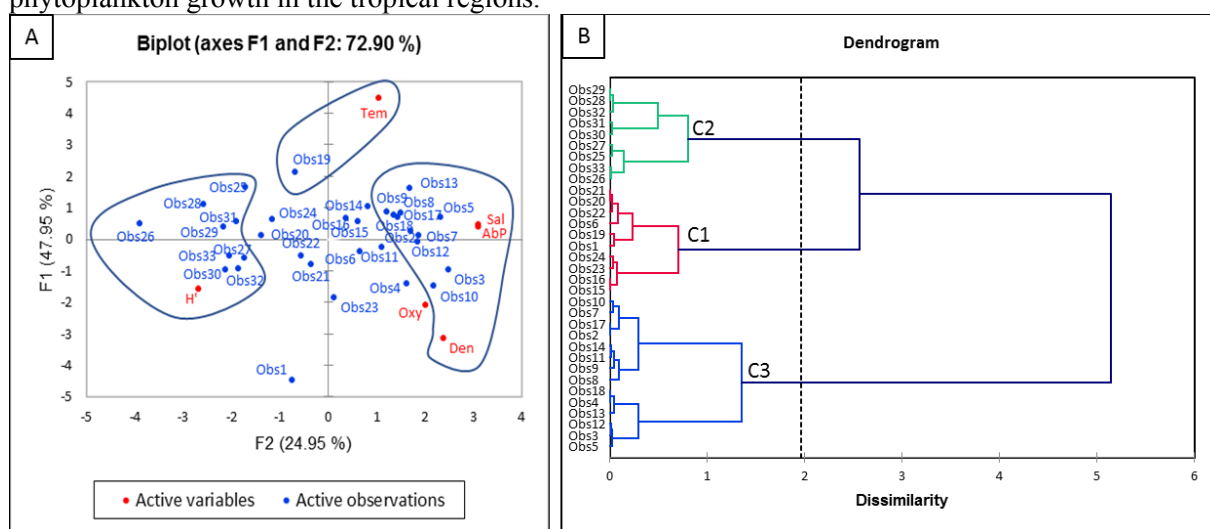


Figure 7. (A) The Principal Component Analysis (PCA) analysis of seawater chemical parameters on the diversity and abundance of phytoplankton. (B) Dendrogram of dissimilarity between stations based on the type and the abundance of phytoplankton

Based on Figure 7B, the inequality analysis is calculated based on the Bray-Curtis inequality index. The results showed significant similarities between observation stations in a very strong category. The three classes (C1, C2, and C3) obtained the thirty-three observation stations showed similarity levels reaching 80.19%. The highest values are shown in C1 with, i.e. stations 1, 6, 15-16, 19-24, which form the first class at 93%, followed by C2, i.e. 2-5, 7-14, 17, and 18, at about 92%, and then C3 of 25-33 stations demonstrated the closest similarity to at 87%. These results show the existence of a high level of similarity in almost all observation stations, which indicates similarity in the source of the phytoplankton abundance and diversity in the upper layer of the Sangihe-Talaud waters.

4. Discussion

The upper layer of Sangihe-Talaud is shown to be influenced by the Indonesian Throughflow (ITF) [16], seamount volcanoes activity, and the mainland of Sulawesi. The temperature, salinity, and density distribution are slightly increased in seamount volcanic activity areas compared to areas near the Pacific Ocean. It was reported by [9, 10] that there is an influence by the volcanic seamount activity to increasing of temperature, salinity, and nutrient. However, the oceanography parameters values found the narrow range and considered to have no effect on phytoplankton growths [4-6, 17].

Phytoplankton composition is found in three classes, with 28 genera. The Bacillariophyceae class is shown very dominantly, especially the genera *Leptocylindrus* and *Guinardia*. For the *Dinophyceae* class, there are many Mesoporous genera. The *Cyanophyceae* class is found in only one genus, *Tricodesmium*. The *Bacillariophyceae* has been reported dominating the Parangipettai coastal waters, Bay of Bengal [18]. The total phytoplankton species reported is low in the Eastern Harbor waters of Alexandria [7], In a Moroccan shallow reservoir [19], In a coastal upwelling zone along western Taiwan Strait [20], but higher than reported in Maspari Island, south Sumatra [21].

The distribution of phytoplankton abundance was found lower in the northern parts of Talaud island, which is likely influenced by the Pacific Ocean's water masses. In contrast, it is higher in the southern parts of Sangihe island, closed to the Sulawesi mainland and the Maluku Channel. There is a nutrient effect from the land. The increasing nutrients influenced the increase of phytoplankton growths [22-28]. Contrarily, the nutrient-poor condition has affected on low phytoplankton growths [29]. However, according to [30], they can grow and reproduce in the nutrient-poor seawater, since they can use phosphonates as a source of phosphorus during metabolic processes. The changes in phytoplankton community structure and distribution of phytoplankton abundance during the monsoon transition period in the Lembeh Strait, North Sulawesi are mainly affected by nutrients. Phytoplankton diversity is generally indicated in the medium category. This means that the water conditions are in good condition for phytoplankton growths, which is also supported by no species that dominate.

The correlation between oceanographic parameters with abundance and the type of phytoplankton is the identifier by temperature, salinity, dissolved oxygen, and density, where it is determined to the abundance of phytoplankton in the southern part of Sangihe-Talaud surface waters. These parameters are the same as the one reported by [21, 31-33], while in [27], the nutrient limitation of phytoplankton communities may change depending on the salinity levels. Therefore, both salinity and nutrient supply must be considered when making water quality threshold for hypersaline systems such as in the Great Salt Lake.

The similarity index indicated a very strong value. It is explained that the phytoplankton abundance and diversity at almost all observation stations have no significant difference. On the contrary, the species and the abundance are found to be very strong in the coastal regions, such as in bays, estuaries, straits and large river mouths, and so on [34-38].

5. Conclusions

Phytoplankton composition in the upper layer of Sangihe-Talaud water has three classes, namely *Bacillariophyceae* for 10 genera, *Dinophyceae* for 17 genera, and *Cyanophyceae* for only one genus, i.e. *Thricodesmium*. The distribution of phytoplankton abundance is higher in the southern parts of the

Sulawesi mainland and the Maluku Channel than in the northern parts, due to is directly connected with the Pacific Ocean of northern part. Phytoplankton diversity is categorized as moderate and no species domination. Correlation between oceanographic parameters with the phytoplankton abundance and diversity is the identifier by salinity, density, and temperature, with a very strong similarity index.

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