The study of phytoplankton in the Banggai Deep Sea: the study case of Banggai Upwelling Dynamics and Ecosystem Experiment (BUDEE)

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Abstract. The upwelling process in the Banggai deep-sea water occurs yearly during the east monsoon. The upwelling process is characterized by low surface water temperatures compared to the surrounding waters, high nutrient values of phosphate, nitrate, and silicate, and high values of primary productivity. The aim of this research was to determine the types of phytoplankton that are abundant in the Banggai deep-sea waters during the upwelling process. Phytoplankton sampling was conducted at 36 stations using a phytoplankton net from a depth of 150 m to the water surface. The mesh size of the phytoplankton net was 80 µm with a net length of 100 cm. Phytoplankton samples were preserved using 4% formalin. Based on the research results, the highest total abundance of phytoplankton was found at station 13 (315,457 cells.m⁻³), followed by stations 20 (234,746 cells.m⁻³), 26 (213,865 cells.m⁻³), station 14 (202,371 cells.m⁻³), station 18 (196,983 cells.m⁻³) and station 46 (187,397 cells.m⁻³). Meanwhile, the other stations had an abundance of <150,000 cells/m³. The highest abundance at station 13 was dominated by the genera Bellerochea (64,068 cells.m⁻³), Chaetoceros (42,407 cells.m⁻³) and Nitzschia (35,390 cells.m⁻³). The high abundance of phytoplankton at Station 13 was due to upwelling.

1 Introduction

Phytoplankton play a vital role as a primary producer of seawater. The ability of phytoplankton to photosynthesize can control the primary productivity rate in seawater. Primary productivity depends on several factors including phytoplankton abundance. The existence of phytoplankton is directly and indirectly influenced by the physicochemical properties of water [1]. Therefore, phytoplankton is not only one of the main producers of water, but can also be used as a bioindicator of water quality and nutrient status in seawater [2].

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Banggai, Central Sulawesi, is located east of Central Sulawesi Province and is classified as high-nutrient (eutrophic) water. The waters of the Banggai Deep Sea are fertile, with numerous fish species and other marine organisms [3]. A complex ecosystem and dynamic flow patterns between islands and activities in the archipelago influence nutrient levels and provide information regarding water quality and distribution. The primary source of nutrients is various terrestrial wastes, which consist of anthropogenic wastes containing organic compounds and are discharged into seawater via rivers [4]. Nutrients from the seabed can reach the surface of water through buoyancy. Therefore, this upwelling will lead to an increase in phytoplankton abundance. The distribution of phytoplankton is extensive, ranging from the coastal waters to the sea. Many nutrients in the body of water can lead to algal blooms. Blooming algae can also cause oxygen starvation, resulting in low or depleted DO levels [5]. This study aimed to identify and study phytoplankton richness in Banggai deep-sea waters in Central Sulawesi.

To date, phytoplankton in deep-sea waters has not been extensively researched. Banggai waters are deep-sea waters in which upwelling occurs. The upwelling process in a body of water influences the hydrology, nutrient levels, and presence and abundance of phytoplankton. Phytoplankton conditions, including abundance, diversity, uniformity, and dominance, are influenced by atmospheric factors, location, and environmental conditions. Upwelling in Banggai waters can result in high nutrient levels and low surface temperatures compared with the surrounding area. High nutrient content in the body of water can lead to an overabundance of phytoplankton. Therefore, it is necessary to explore their identification, abundance, diversity, evenness, and dominance.

2 Materials and method

This research is part of the Banggai Upwelling Dynamic Ecosystem Experiment expedition conducted by the IPB, UI, UNDIP, UNPATTI, P2O-LIPI (PRO-BRIN), and BRIN Geology and Atmosphere Research Center. Phytoplankton sampling was conducted at 36 sampling sites in Banggai deep-sea waters in Central Sulawesi (Fig. 1). Phytoplankton samples were collected from September 1 to 15, 2022, using BRIN's research vessel Baruna Jaya VIII (P2O LIPI).

Fig. 1. Sampling stations for phytoplankton study in the Banggai Archipelago, Sulawesi, Indonesia.
The phytoplankton net has a mesh size of 80 µm, length of 100 cm, and net opening diameter of 50 cm [6]. Phytoplankton were collected vertically from 150 m to the water surface. The phytoplankton samples were then preserved in 4% formalin, corresponding to one-tenth of the sample volume for phytoplankton observations under a light microscope at 100x magnification. Identification was performed using references [7,8]. Phytoplankton counting using the Sedgwick Rafter.

2.1 Sample analysis

Calculation of phytoplankton abundance uses the following formula:

\[ A = n_i \times \left( \frac{V_t}{V_{src}} \right) \times \left( \frac{1}{V_d} \right) \]

Note: \( A \) = Abundance of Phytoplankton1 (cells.m\(^{-3}\)); \( n_i \) = sum of enumeration result (cell); \( V_t \) = Volume of sample (m\(^3\)); \( V_{src} \) = volume of sedgwick after counting cell; \( V_d \) = Volume of filtered water (m\(^3\))

The abundance of phytoplankton can be an indication of the fertility of a body of water. An abundance of <2000 cells/m\(^3\) is considered oligotrophic. If the abundance value is 2000 – 15,000 cells/m\(^3\), the water is mesotrophic. The waters were classified as eutrophic if their abundance was > 15,000 cells/m\(^3\). The diversity index, evenness index, and dominance index were calculated based on a formulation by Shannon Wiener [9-11].

2.2 Data analysis

The Ceratium Genus Diversity Index can be calculated using the Shannon-Wiener formula [9, 10, 18].

\[ H' = -\sum p_i \ln p_i \]

Note: \( H' \) = Diversity Index; \( p_i \) = Number of cell species observed/total number of all species (\( n_i/N \)), where \( n_i \) is the number of individuals in taxon I and \( N \) is the total number of individuals in the community. A diversity index value of \( H' < 1 \) indicates low community stability, 1<\( H' < 3 \) indicates moderate community stability, and \( H' > 3 \) indicates high community stability [9, 10, 18].

The Evenness Index can be calculated using the following formulas [9, 10, 18]:

\[ E = \frac{H'}{\ln (S)} \]

Note: \( E \) = evenness index; \( S \) = number of species found; \( \ln \) = natural logarithm. The Evenness index value \( E > 0.6 \) indicates an even level of Evenness, and the species in the community is increasingly spreading; 0.4<\( E < 0.6 \) indicates fairly even evenness, and \( E <0.4 \) indicates uneven evenness and relatively low species richness [9, 10, 18].

The Dominance Index was calculated using the following formula [9, 10, 18].

\[ C = \sum_{i=1}^{n} \left[ \frac{n_i}{N} \right]^2 \]

Note: \( D \) = Dominance Index; \( n_i \) = number of cells of the species observed; \( N \) = Total number of all species; the dominance index (D) value that is close to 1 indicates that there is a species that dominates the community, while a D value close to 0 indicates that there are no species that dominate the community [9, 10, 18].
3 Results and discussion

3.1. Phytoplankton abundance and distribution

Based on the results, in the Banggai Deep Sea, phytoplankton were dominated by the diatom classes Bacillariophyceae (65%), Dinophyceae (26%), Cyanophyceae (6.5%), and Dictyochophyceae (2.5%). There were 31 genera of diatoms (Class Bacillariophyceae), 12 genera from Class Dinophyceae, 3 genera from Cyanophyceae, and 1 genus from class Dictyochophyceae. There are 47 genera of phytoplankton identified in the Banggai deep-sea waters. The genera found in the Banggai Deep Sea were more abundant than the number of phytoplankton types found in the Banda Sea during the East Monsoon. In 1998, 33 species of this genus were recorded [12]. Diatoms and Dinophyceae are also abundant in Holtekamp, Jayapura City, part of eastern Indonesian waters [19]. This indicates that there was an upwelling process during the east monsoon in the Banggai Deep Sea Waters and Banda Sea waters.

The total abundance of phytoplankton was greater than $10^4$ cells.m$^{-3}$, found at stations 11, 13, 14, 18, 20, 21, 26, 27, 38, 45, and 26. The highest abundance of phytoplankton was found at station 13 (31,5 x $10^4$ cells.m$^{-3}$), followed by station 20 (234,746 cells.m$^{-3}$), station 26 (213,865 cells.m$^{-3}$), station 14 (202,371 cells.m$^{-3}$), station 18 (196,983 cells.m$^{-3}$) and station 46 (187,397 cells.m$^{-3}$). Meanwhile, other stations had abundance values of < 15x10$^4$ cells.m$^{-3}$ (Fig. 2). The highest abundance at station 13 was dominated by the genera Bellerochea (64,068 cells.m$^{-3}$), Chaetoceros (56,949 cells.m$^{-3}$) and Nitzschia (35,390 cells.m$^{-3}$). The abundance value at station 13 was 315,457 cell.m$^{-3}$ because station 13 was a sampling site for upwelling (Fig. 2). Similarly, at Stations 11, 14, and 26. The upwelling process that occurred at several sampling sites resulted in high nutrient values and low surface water temperatures [16, 17]. The highest abundance value of Chaetoceros was found at station 14 (56,949 cells.m$^{-3}$) followed by station 13 with an abundance value of 42,407 cells.m$^{-3}$. The highest value for Planktoniella abundance was 20,136 cells.m$^{-3}$ (station 13), followed by station 11 (16,169 cells.m$^{-3}$). The highest abundance Coscinodiscus at station 13, with a value of 22,881 cells.m$^{-3}$ (Table 2-5). The highest abundance value for Nitzschia was at station 13 (35,390 cells.m$^{-3}$) followed by station 14 with a value of 30,763 cells.m$^{-3}$ (Table 1-5). This shows that upwelling affects the abundance of phytoplankton Chaetoceros, Planktoniella, Coscinodiscus, and Nitzschia.

The highest abundance of phytoplankton was found at station 34 (320x104 cell.m$^{-3}$) and the lowest abundance was found at station 54 (4x104 cell.m$^{-3}$). This shows that Banggai waters have mesotrophic and eutrophic fertility. The abundance of phytoplankton indicates the fertility of waters; an abundance value < 2,000 cell.m$^{-3}$ is oligotrophic (low), 2,000 – 15,000 cell.m$^{-3}$ is eutrophic (medium), and > 15,000 cell.m$^{-3}$ is high eutrophic [3]. The abundance of phytoplankton is greatly influenced by nutrients, salinity, brightness, pH, and temperature in the context of upwelling plankton, which also influences the abundance and quality of water [19].

The genera Bellerochea are often found at stations 11 (29,898 cells.m$^{-3}$), 18 (56,186 cells.m$^{-3}$), 20 (75,424 cells.m$^{-3}$), 21 (32,881 cells.m$^{-3}$), 24 (27,983 cells.m$^{-3}$), 38 (43,119 cells.m$^{-3}$), 45 (27,407 cells.m$^{-3}$), and 46 (36,356 cells/m3 (Table 1-5). The abundance of Bellerochea at this station supports the conditions required for primary productivity. This diatom group is very popular for natural fish because it Bellerochea has thin cell walls, is made of silicate, and is easily digested by fish [14]. Bellerochea belongs to the family Bellerocheaceae, order Biddphiales, and class Bacillariophyceae [13,14].
Based on the research results, the abundance of diatoms is greater than that of dinoflagellates, which is related to the large silicate content. This is also in accordance with research showing that nutrient content greatly determines the abundance of diatoms and dinoflagellates (Dinophyceae) [15-16].

The abundance of Ceratium (Class Dinophyceae) was found at almost all stations, except station 27. The greatest abundance of Ceratium was at station 11, with an abundance value of 10,983 cells.m$^{-3}$. The abundance value at station 11 (104,338 cells.m$^{-3}$) exceeds 15,000 cells.m$^{-3}$, this means that station 11 was classified as eutrophic. All observation stations were classified as eutrophic waters except stations 47, 49, 53, 54, 56, 57, and 59 (Table 1-5) which were classified as meso-tropic waters. This is in accordance with the fact that waters at the meso-tropic level have phytoplankton abundance values ranging from 2,000 to 15,000 cells.m$^{-3}$. The high abundance of phytoplankton at several stations in the Banggai Deep Sea Waters is due to upwelling events occurring in these waters. The upwelling phenomenon is characterized by an increase in water mass from the bottom of the water to the surface of the water, which is characterized by high values of phosphate, nitrate, and silicate content [17].
Table 1. The abundance of Phytoplankton (cells.m$^{-3}$) in the Deep Sea Banggai Waters (Station 1–16).

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Table 2. The abundance of Phyttoplankton (cells.m$^{-3}$) in the Deep Sea Banggai Waters (Station 18-27).

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<td>46.</td>
<td>Pelagoothrix</td>
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3.2. Ecology index phytoplankton in Deep Sea-Banggai Waters

Based on the results of the community structure analysis, the range of diversity index values was 2.01 – 2.83, the range of evenness index values was 0.04 – 0.06, and the range of dominance index values was 0.07 – 0.24 (Fig. 2-3). Based on the range of diversity index values, it can be concluded that the Banggai Deep Sea waters have a phytoplankton community with moderate diversity, low evenness values, no dominant phytoplankton, and the aquatic ecosystem is in a stable condition. Based on the diversity index value, the phytoplankton community is categorized as meso-tropic [10].

The highest diversity index value was found at station 55 (2.83), followed by stations 34 (2.81), 56 (2.77), and 23 (2.74), respectively. All observation stations have a diversity value above 2.01, which shows that the phytoplankton population in the community is diverse and the ecosystem is moving towards balance and stability. A diversity index value between 2 and 3 indicates moderate community stability [9, 10, 18]. This shows that Banggai deep-sea waters have moderate to high diversity. This is also in accordance with the results of research on the Banggai Islands, which showed moderate diversity values [21]. Based on several studies, the high seas are classified as waters with low productivity, known as oligotrophic [21], unless the upwelling process occurs in these waters [20].

According to the results, all stations had a low evenness index. The range of the evenness index values for all observation stations is 0.05 to 0.06. High diversity values were followed by low evenness indices. This shows that Banggai deep-sea waters have a stable population level in the aquatic ecosystem. This is also in accordance with the results of research in Banggai waters, which showed low evenness index values [21]. When associated with the dominant index value, which ranges from 0.07 – 0.28, there are no dominant phytoplankton organisms in the Banggai deep-sea waters. Analysis showed that the Banggai deep sea has a diverse population of phytoplankton, and there are no dominant species. This is also in accordance with research on the Banggai Islands, which has a low evenness value [21].

![Diversity Index of Phytoplankton for 36 stations in Deep Sea Banggai Waters.](image-url)
Fig. 4. Evenness Index of Phytoplankton for 36 stations in Deep Sea Banggai Waters.

Fig. 5. Dominance Index of Phytoplankton for 36 stations in Deep Sea Banggai Waters.
3.3. Impact of upwelling dynamics

Upwelling is the process of raising water masses from a certain depth to the water surface. Upwelling is characterized by low sea surface temperatures in these waters compared to surrounding waters, high chlorophyll-a content, and high nutrient values [20]. The large number of islands in Indonesia causes complex currents and upwelling in several water areas in Indonesia [20]. Based on the findings of this study, upwelling occurred around Stations 13 and 11. This was proven by the large abundance of phytoplankton at station 13 (316 x 104 cell.m$^{-3}$). The presence of water masses that rise from a certain depth to the surface of the water causes high values of nutrient content (Phosphate, Silicate, and Nitrate), which in turn can increase phytoplankton abundance [20].

The Banggai deep sea is eutropic because these waters are traversed by Indonesian cross-currents that meet currents from the Banda Sea. The combination of these two currents greatly influences the water productivity in the Banggai Deep Sea [20]. Additionally, the east monsoon causes sea currents from the southeast direction originating from the Banda Sea, creating a current pattern from under the sea to the sea surface, which carries many nutrients that phytoplankton really need to grow and develop.

However, research in the waters of the Banggai Islands shows that there is no correlation between nutrient availability and phytoplankton abundance [22]. Pearson correlation analysis showed that the nutrient content did not significantly determine the abundance and distribution of phytoplankton [22]. However, upwelling has many effects on the existence, abundance, and distribution of phytoplankton [20-22].

4 Conclusion

The main features that characterize the upwelling process in the deep-sea waters of Banggai are (1) low surface water temperatures compared to the surrounding waters, (2) high nutrient levels of phosphate, (3) nitrate and silicate, and high primary productivity. In the deep-sea waters of Bangai, 31 genera of diatoms (class Bacillariophyceae), 12 genera from class Dinophyceae, three genera from class Cyanophyceae, and one genus from class Dictyochophyceae were found. Based on the identification results, 47 phytoplankton genera were identified in the deep-sea waters of Banggai. The highest phytoplankton abundance was found at station 13, with a value of 315,457 cells per cubic meter, and was dominated by the genus Bellerochea. The genera found at all the sampling sites were Chaetoceros, Planktoniella, Coscinodiscus, and Nitzchia. Based on ecological index analysis, the phytoplankton community exhibited moderate diversity, low evenness, and no dominance. The ecosystem in the Banggai deep sea has moderate community stability. Therefore, it was classified as mesotrophic water based on its diversity index value.

We thank BRIN, IPB University, UI, UNPATTI, and UNDIP for supporting this research. We would like to thank you very much for the laboratory team at the Marine Biology Laboratory for their assistance. Department of Marine Sciences, Faculty of Fisheries and Marine Sciences.

References