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

Widianinigsih Widianingsih[1,*], *Retno* Hartati[1], *Agus* Saleh Atmadipura[2], and *Rina* Zuraida[3]

[1]Department of Marine Sciences, Faculty of Fisheries and Marine Sciences, Diponegoro University, Semarang 50275, Central Java, Indonesia
[2]Department of Marine Sciences and Technology, Faculty of Fisheries and Marine Sciences, IPB University, Bogor 16680, West Java, Indonesia
[3]Center for Climate and Atmospheric Research, National Research and Innovation Agency

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 (187397 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].

* Corresponding author: widia2506@gmail.com

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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).

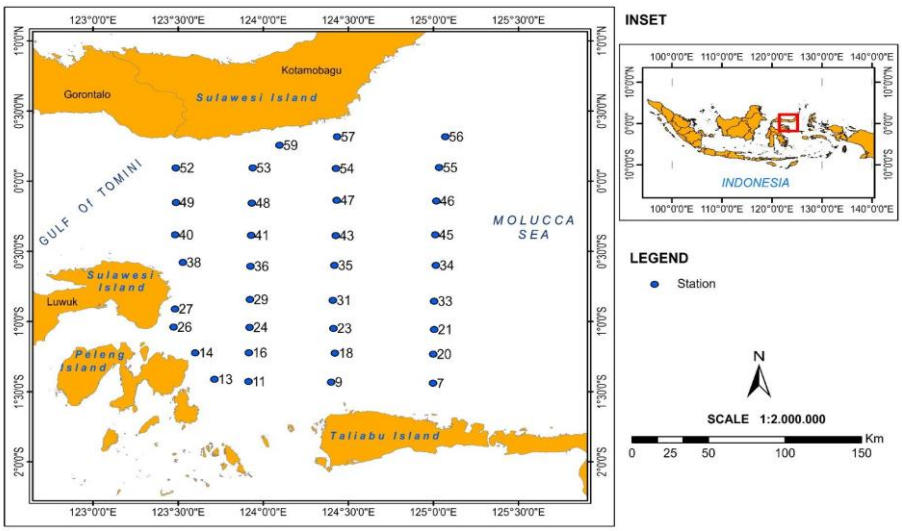

Fig. 1. Sampling stations for phytoplankton study in the Banggai Archipelago, Sulawesi, Indonesia.

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 :

$$A = ni \times (V_t / V_{src}) \text{ x } (1/ V_d) \quad (1)$$

Note: A = Abundance of Phytoplankton1(cells.m^{-3}); ni = sum of enumeration result (cell); V_t = Volume of sample (m^3); Vsrc = volume of sedgwick after counting cell); Vd =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 mesotropic. 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].

$$H' = -\sum pi \ln pi \quad (2)$$

Note: H' Diversity Index; pi: Number of cell species observed/total number of all species (ni/N). where ni 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]:

$$E = \frac{H\prime}{\ln (S)} \quad (3)$$

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].

$$C = \sum_{i=1}^{n} \left[\frac{n_i}{N}\right]^2 \quad (4)$$

Note: D: Dominance Index; ni: 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 x10^4 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 mesotropic and eutropic fertility. The abundance of phytoplankton indicates the fertility of waters; an abundance value < 2,000 cell.m^{-3} c 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 cell.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 Bidduphiales, and class Bacillariophyceae [13,14].

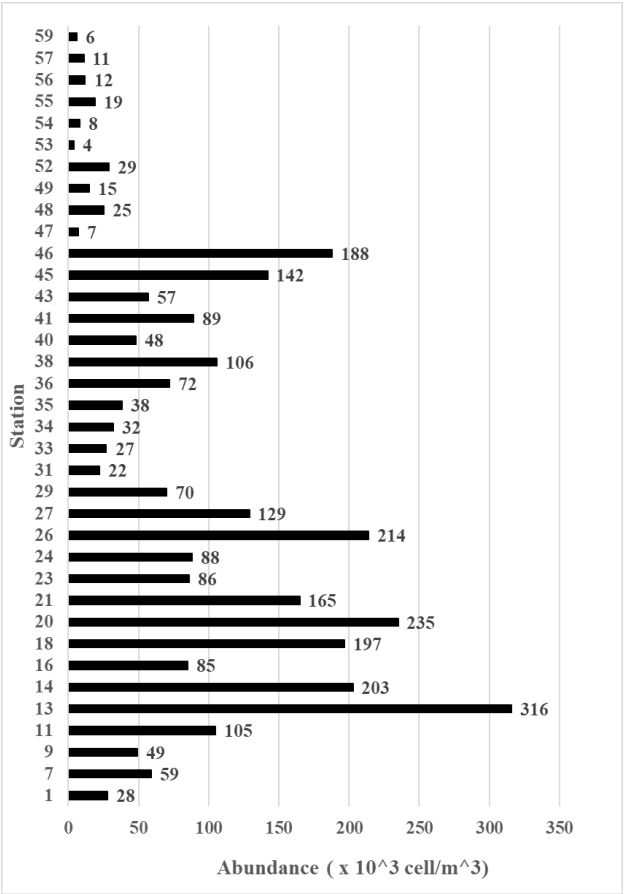

Fig. 2. Total Abundance (x10^3 cells.m^{-3}) Phytoplankton on 36 sampling stations in Banggai Waters.

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).

No	Taxonomy	Station						
		1	7	9	11	13	14	16
1.	*Lauderia*	508						
2.	*Planktoniella*	678	6,864	9,594	16,169	20,136	8,644	5,695
3.	*Skeletonema*		2,034					
4.	*Thalassiosira*							
5.	*Melosira*	1,864	5,847	1,017		4,271	1,017	
6.	*Stephanopysis*			2,034				
7.	*Leptocylindrus*			3,051		1,525	1,780	1,220
8.	*Coscinodiscus*	3,220	11,44	8,475	12,508	22,881	109,32	8,542
9.	*Asterolampra*							2,847
10.	*Asteromphalus*							
11.	*Aulacosdiscus*							
12.	*Rhizosolenia*	678	2,288		1,220	16,169		4,475
13.	*Euchampia*	1,017	1,780	2,373	1,220	2,746	1,525	1,627
14.	*Hemialus*							
15.	*Climacodium*							
16.	*Cerataulina*							
17.	*Bellerochea*				29,898	64,068		
18.	*Ditylum*							
19.	*Odontella*				305			
20.	*Biddulphia*	508				2,441	2,288	
21.	*Bacteriastrum*	508	2,288		915	1,220	3,559	4,881
22.	*Chaetoceros*	1,864	3,814	3,390	3,966	42,407	56,949	3,661
23.	*Psudonitzschia*		763	2,373	915	2,136	3,559	3,661
24.	*Nitzschia*	3,898	3,051	3,051	5,492	35,390	30,763	18,71
25.	*Triceratium*					1,525	1,271	
26.	*Thalassionema*	7,288			5,492	47,288	29,492	5,695
27.	*Thalassiothrix*	1,356	3,305		5,797	14,644	22,627	4,881
28.	*Pleurosigma*							
29.	*Navicula*							2,847
30.	*Bacillaria*							
31.	*Amphisolenia*							
32.	*Dinophysis*							
33.	*Ornithocercus*							
34.	*Noctiluca*	1,186	2,034	1,695	2,136	4,576	508	
35.	*Ceratium*	169	6,102	3,309	10,983	9,763	7,119	1,627
36.	*Ceratocorys*							
37.	*Pyrodinium*							
38.	*Gonyaulax*							
39.	*Pyrocystis*		1,017	3,390	2,136	2,746	1,780	5,288
40.	*Pyrophacus*							
41.	*Peridinium*		508	1,695	1,525	1,525	508	1,220
42.	*Proroperidinium*							
43.	*Dictyocha*				305	1,525	1,017	
44.	*Microcystis*	2,712	5,847	2,712	3,051	16,475	23,898	6,102
45.	*Tricodesmium*				305		3,559	1,220
46.	*Pelagothrix*						508	

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

No	Taxonomy	Station						
		18	20	21	23	24	26	27
1.	*Lauderia*							
2.	*Planktoniella*	8,644	8,475	4,068	4,475	3,085	4,407	4,068
3.	*Skeletonema*			5,085	2,237			
4.	*Thalassiosira*							
5.	*Melosira*	11,780	14,237	12,712	13,661	1881		
6.	*Stephanopysis*					12,864	16,169	11,017
7.	*Leptocylindrus*	19,915	116,525	19,492	18,542	13,746	12,203	17,119
8.	*Coscinodiscus*	17,881	118,644	111,186	110,78	115,644	118,068	117,966
9.	*Asterolampra*	1763	11,695				1881	1678
10.	*Asteromphalus*							
11.	*Aulacosdiscus*			11,017				
12.	*Rhizosolenia*	13,305	113,559	17,797	14,271	13,305	110,136	16,780
13.	*Euchampia*	128,220	113,983	113,898	11,831		13,085	11,017
14.	*Hemialus*							11,017
15.	*Climacodium*							
16.	*Cerataulina*							
17.	*Bellerochea*	156,186	175,424	132,881	18,542	127,983	116,746	17,119
18.	*Ditylum*							
19.	*Odontella*							
20.	*Biddulphia*	11,780		11,017	11,017	1661	11,763	
21.	*Bacteriastrum*	11,627	11,695	12,373	1610			
22.	*Chaetoceros*	17,322	116,949	113,898	18,949	17,932	140,983	111,864
23.	*Psudonitzschia*		12,542	15,424		14,627	15,288	
24.	*Nitzschia*	115,051	115,254	120,678	19,356	15,288	112,339	115,932
25.	*Triceratium*	1763		1678	1203		1441	11,695
26.	*Thalassionema*	18,136	15,085	13,051	11,627	11,322	163,017	120,000
27.	*Thalassiothrix*	114,237	12,119	15,424	13,661	13,746	118,949	114,237
28.	*Pleurosigma*							
29.	*Navicula*	1814	11,271	11,017	1407		1881	11,017
30.	*Bacillaria*							
31.	*Amphisolenia*							
32.	*Dinophysis*							
33.	*Ornithocercus*							
34.	*Noctiluca*		1847	1678			1881	
35.	*Ceratium*	13,254	15,085	13,390	1610	13,085	12,203	
36.	*Ceratocorys*							
37.	*Pyrodinium*							
38.	*Gonyaulax*		11,271		1203			
39.	*Pyrocystis*	113,831	114,407	14,407	14,068	13,085	13,966	14,746
40.	*Pyrophacus*				1610			12,712
41.	*Peridinium*	12,847	12,119	12,373	11,627	1661	11,322	
42.	*Proroperidinium*							
43.	*Dictyocha*	11,271	11,695				18.81	144.07
44.	*Microcystis*	17,322	19,746	17,458	16,102	148.47	1101.36	44.07
45.	*Tricodesmium*	12,034	12,119	14,068	12,441	124.24	126.44	113.56
46.	*Pelagothrix*							

Table 3. The abundance of Phytoplankton (cells.m^{-3}) in the Deep Sea Banggai Waters (station 29-38).

No	Taxonomy	Station						
		29	31	33	34	35	36	38
1.	*Lauderia*							
2.	*Planktoniella*	13,915	13,220	13,814	13,169	12,712	14,322	13,864
3.	*Skeletonema*							
4.	*Thalassiosira*		1508					
5.	*Melosira*					1678	11,017	
6.	*Stephanopysis*	1746					12,034	1814
7.	*Leptocylindrus*	16,898	12,373	11,678	12,610	1508	12,542	11,424
8.	*Coscinodiscus*	117,525	13,390	11,831	15,220	13,051	114,75	15,695
9.	*Asterolampra*			1305		1169		
10.	*Asteromphalus*	1186			1186			
11.	*Aulacosdiscus*							
12.	*Rhizosolenia*	14,102	13,729	1610	11,492	11,525	11,271	12,847
13.	*Euchampia*	114,169	1508		11,678	19,831	11,525	1610
14.	*Hemialus*		1678					
15.	*Climacodium*							
16.	*Cerataulina*							
17.	*Bellerochea*	15,966		14,119	11,492	14,237	111,95	143,119
18.	*Ditylum*							
19.	*Odontella*							
20.	*Biddulphia*	1746					11,017	1814
21.	*Bacteriastrum*	1186						
22.	*Chaetoceros*	14,661	11,017	11,831	11,492	11,864	12,542	18,746
23.	*Psudonitzschia*		1678			11,525		11,424
24.	*Nitzschia*	12,610	11,695	11,068	14,102	12,712	17,373	15,085
25.	*Triceratium*	1186		1153	1559		1254	1610
26.	*Thalassionema*			1763	1559		11,780	114,441
27.	*Thalassiothrix*	12,424	11,356	14,271	11,492	11,017	11,780	16,305
28.	*Pleurosigma*				1559			
29.	*Navicula*							
30.	*Bacillaria*							
31.	*Amphisolenia*		1339		1186	1339		1203
32.	*Dinophysis*		1169	1305	1932	12,712	12,288	11,220
33.	*Ornithocercus*							
34.	*Noctiluca*		1508		1186			1814
35.	*Ceratium*	11,305	1339	13,508	12,610	12,034	11,271	13,661
36.	*Ceratocorys*							
37.	*Pyrodinium*							
38.	*Gonyaulax*							
39.	*Pyrocystis*	13,542	1678	11,525	12,983	12,373	112,71	12,847
40.	*Pyrophacus*			1763	1373			1610
41.	*Peridinium*	1186	1339				11,017	1610
42.	*Proroperidinium*				111	110		
43.	*Dictyocha*	17.46	15		111	112	158	
44.	*Microcystis*	135.42	137.29	132.03	124.24	116.95	130.51	
45.	*Tricodesmium*	120.51	13	13	12		13	114
46.	*Pelagothrix*	11.86						

Table 4. The abundance of Phytoplankton (cells.m^{-3}) in the Deep Sea Banggai Waters (Station 40-48).

No	Taxonomy	Station						
		40	41	43	45	46	47	48
1.	*Lauderia*		1847	1712	12,610	11,525	13,79	14,271
2.	*Planktoniella*	12,644	15,254	13,797	113,424	116,780	12,16	18,847
3.	*Skeletonema*							
4.	*Thalassiosira*							18,847
5.	*Melosira*		1339					
6.	*Stephanopysis*				13,356			
7.	*Leptocylindrus*	13,966	13,390	13,322	13,356	112,712	111	149
8.	*Coscinodiscus*	12,644	110,678	15,932	118,085	116,271	138	185
9.	*Asterolampra*							
10.	*Asteromphalus*							
11.	*Aulacosdiscus*							
12.	*Rhizosolenia*	11,322	16,102	14,508	15,407	110,932	122	158
13.	*Euchampia*	14,407	12,034	110,20	114,356	15,593		
14.	*Hemialus*							
15.	*Climacodium*					13,305	1138	149
16.	*Cerataulina*							
17.	*Bellerochea*	13,085	18,983	17,831	127,407	136,356	1366	11,242
18.	*Ditylum*							
19.	*Odontella*						119	19
20.	*Biddulphia*	1881	1678	1712	1746	1254	18	
21.	*Bacteriastrum*					12,034	13	112
22.	*Chaetoceros*	11,322	114,746	13,322	13,915	111,949	114	1165
23.	*Psudonitzschia*		11,356	1949	1559			
24.	*Nitzschia*	12,644	17,458	13,797	15,593	14,576	18	146
25.	*Triceratium*		1678					
26.	*Thalassionema*		112,034		113,424	123,644	119	1274.58
27.	*Thalassiothrix*	118,508	13,729	13,322	19,136	113,983		1112.88
28.	*Pleurosigma*							
29.	*Navicula*							
30.	*Bacillaria*					13,305		
31.	*Amphisolenia*	1441				11,780	15	19
32.	*Dinophysis*	11,322	1169	1949	12,797	11,525	15	16
33.	*Ornithocercus*						18	13
34.	*Noctiluca*				1559			
35.	*Ceratium*	11,322	15,424	11,661	17,831	17,119	143	143
36.	*Ceratocorys*					11,525		
37.	*Pyrodinium*							
38.	*Gonyaulax*							
39.	*Pyrocystis*	13,085	13,051	14,746	14,475	18,136	133	118
40.	*Pyrophacus*			1712	11,492	12,288	111	16
41.	*Peridinium*		11,186		12,983	11,780		19
42.	*Proroperidinium*	14						
43.	*Dictyocha*	113	12	121	117	123	116	19
44.	*Microcystis*	113.22		114.24	131.69		15	1241
45.	*Tricodesmium*	19	110	119	115	13	15	115
46.	*Pelagothrix*		12	12	12			13

Table 5. The abundance of Phytoplankton (cells.m^{-3}) in the Deep Sea Banggai Waters (Station 49–59).

No	Taxonomy	Station1							
		49	52	53	54	55	56	57	59
1.	*Lauderia*	13,085	111,441			13,322		14,068	1508
2.	*Planktoniella*	16,610	16,780	12,14	15,59	113,288	110,169	14,881	13,05
3.	*Skeletonema*								1847
4.	*Thalassiosira*	12,203							
5.	*Melosira*							124	
6.	*Stephanopysis*	197			126		151	15	17
7.	*Leptocylindrus*	1115	176	115	162	1299	1139	184	149
8.	*Coscinodiscus*	122	147	158	146	1123	1125	171	122
9.	*Asterolampra*								
10.	*Asteromphalus*								
11.	*Aulacosdiscus*								
12.	*Rhizosolenia*	1119	159	115	131	1123	188	1165	144
13.	*Euchampia*	113	113		126		168	1125	158
14.	*Hemialus*					1185	168	176	115
15.	*Climacodium*	184		121	142	147			
16.	*Cerataulina*						154		
17.	*Bellerochea*	1304	1208	1201	1793	1327	195	152	1103
18.	*Ditylum*							18	15
19.	*Odontella*				17			15	
20.	*Biddulphia*	19		19		19	110		
21.	*Bacteriastrum*	118		16	120	133	110	133	17
22.	*Chaetoceros*	1304	1263	1113	1115	1233	192	1491	193
23.	*Psudonitzschia*	148	113	158					
24.	*Nitzschia*	113	113	112	113	138	131	1100	141
25.	*Triceratium*	14		13	19	15			12
26.	*Thalassionema*	1898.98	1101.69	1241	1156	1223		1404	197
27.	*Thalassiothrix*	1149.83	1182.20	164	151	1214	117	176	147
28.	*Pleurosigma*					19			
29.	*Navicula*				12	15			
30.	*Bacillaria*								
31.	*Amphisolenia*	113	113	19	12	114		114	18
32.	*Dinophysis*			13	120	138	110	111	12
33.	*Ornithocercus*	14			14	119	17		12
34.	*Noctiluca*	113					17		
35.	*Ceratium*	144	134	19	129	1109	147	162	122
36.	*Ceratocorys*				12	124		130	
37.	*Pyrodinium*								
38.	*Gonyaulax*								
39.	*Pyrocystis*	166	113	146	19	166	195	143	122
40.	*Pyrophacus*					15		15	
41.	*Peridinium*	113	121			181	117	130	110
42.	*Proroperidinium*			118	17				
43.	*Dictyocha*	14						15	
44.	*Microcystis*	118	147		140	181	1169	149	13
45.	*Tricodesmium*	122	113	118				111	
46.	*Pelagothrix*			19		138	120	111	12

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].

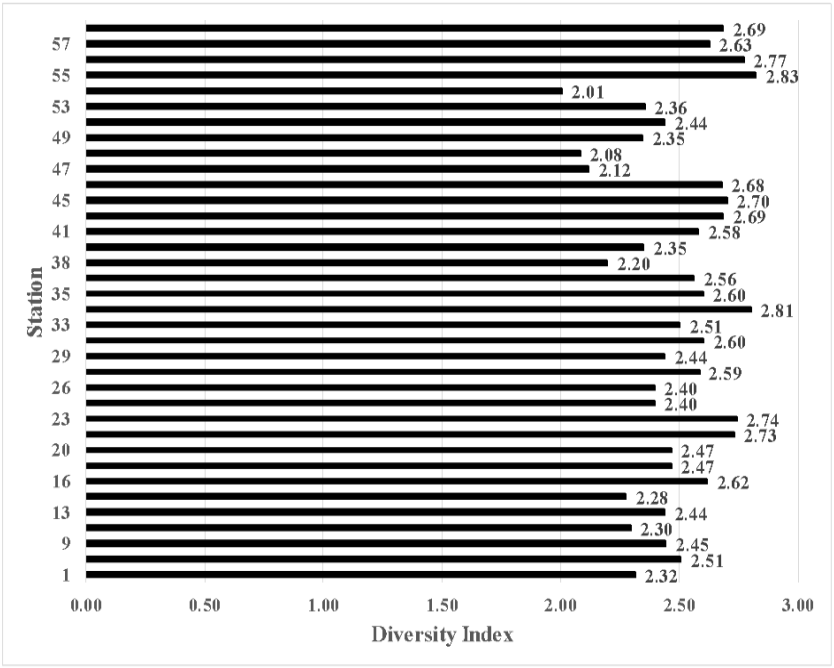

Fig. 3. Diversity Index of Phytoplankton for 36 stations in Deep Sea Banggai Waters.

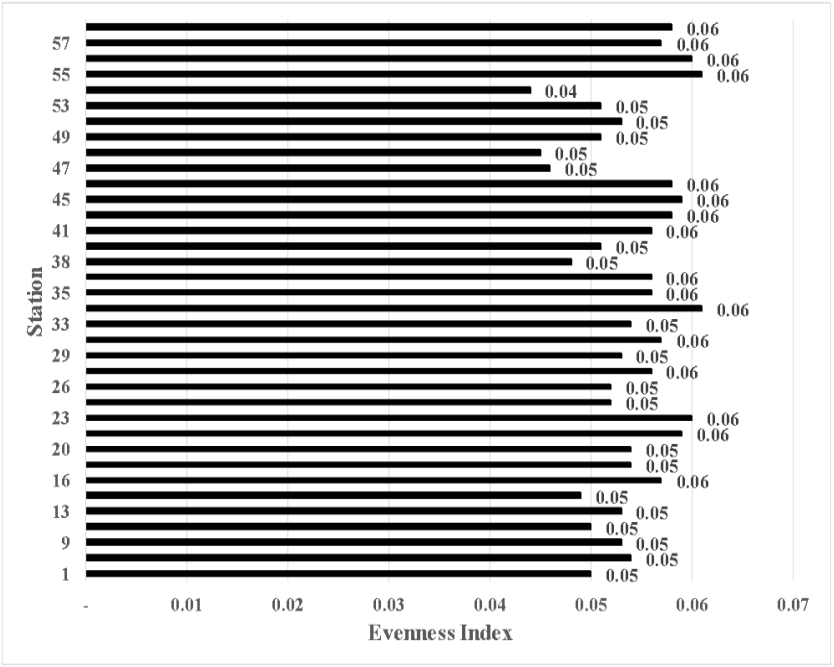

Fig. 4. Evenness Index of Phytoplankton for 36 stations in Deep Sea Banggai Waters.

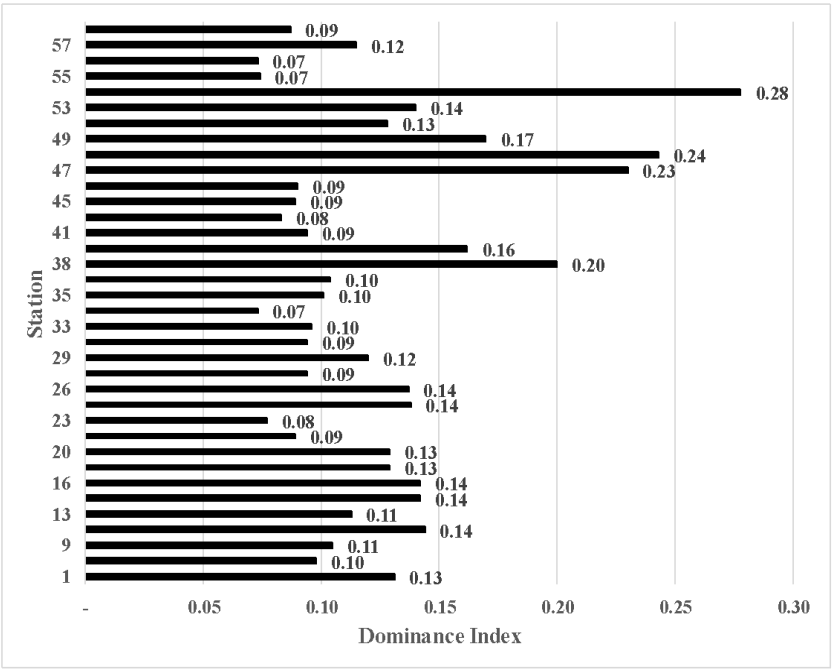

Fig. 5. Dominance Index of Phytoplankton for 36 stations in Deep Sea Banggai Waters.

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.

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