Diversity and Spatial Distribution of Plankton in Connected Waters of Bali Strait, Between Eastern Part of Java and Western Part of Bali Island

NTM Pratiwi, DY Wulandari, IP Ayu, and A Iswantari
Department of Aquatic Resources Management,
Faculty of Fisheries and Marine Sciences, Bogor Agricultural University
Jl. Agatis, Kampus IPB Dramaga, Bogor 16680

E-mail: niken_tmpratiwi@yahoo.com

Abstract. Bali Strait waters located between Java and Bali Island contain high productivity, which indicated by the high diversity of phytoplankton and zooplankton. The purpose of the research was to understand the local (α), intra-space (β), and regional or total (ϒ) diversity values (that expressed as richness) of plankton taken from surface and thermocline layers. The surface observation was carried out at three locations, two locations, with 5 stations of each, nearshore (Banyuwangi/Jawa Island and Southern part of Bali Island) and one location, with 9 stations, offshore (Bali Strait). The thermocline was observed offshore at all 9 stations as the surface. The diversity of each stations (α) were 11-20 for phytoplankton and 7-12 for zooplankton at the surface, then 9-11 and 7-13, respectively at the thermocline. The total diversity (ϒ) of phytoplankton was 27 and 13 of zooplankton. Based on the β values, the plankton of nearshore were also found at offshore locations. Furthermore, some species of plankton at the surface were not found in thermocline layer. As a whole, phytoplankton and zooplankton were well distributed at the surface, but showed as specific distribution at thermocline layer, especially for phytoplankton.

1. Introduction

Bali Strait located between Java Island and Bali Island connects two waters, i.e. Bali Sea in the north and Indian Ocean in the south. It contain high productivity of fish [1] which is also indicated by a high the diversity of plankton, both phytoplankton and zooplankton [2].

Plankton is microscopic organism, both animals and plants, which drift with the flow [3]. Some types of plankton can swim only passively, not at all move, and others swam quite active [4]. Plankton consists of phytoplankton and zooplankton. Phytoplankton is an autotrophic microorganism which able to produce organic matter from inorganic material through the process of photosynthesis with the help of light. Approximately 95% of primary production in the ocean comes from phytoplankton [5]. Furthermore, zooplankton plays an important role in aquatic food webs, both as a resource for consumers on higher trophic levels and as a conduit for packaging the organic material in the biological pump [6].

Phytoplankton and zooplankton communities are distributed either horizontally or vertically in all waters. Distribution of phytoplankton is influenced by physical factors such as the mass movement of water and chemicals, such as nutrients. In addition, zooplankton can rely on water currents to move any great distance.

The presence of phytoplankton is highly correlated to photic and warmer water layer, while zooplankton might be present more at lower water layer. Meanwhile, the water quality and mass water movement could influence the presence of those plankton communities in the water layer.

The thermocline is a unique layer that shows a colder and thicker water, that gives specific condition, such as organic matterials accumulation and nutrients availability that could serve as living area for both phytoplankton and zooplankton.

Study of diversity and spatial distribution of plankton are important to develop. Therefore, the purpose of this research was to understand the local, intra-space diversity, and regional (total) diversity or α, β, and γ diversity.

2. Material and Methods

2.1. Study area

This research was conducted in February-March 2011 using the Research Vessel Baruna Jaya VIII of Oceanography Research Center, Indonesian Institute of Sciences (P2O-LIPI). Sampling of plankton and water quality parameters were taken once at a predetermined location (Figure 1). At the surface water, the observation was carried out at three locations, two nearshore (Banyuwangi/Eastern part of Java Island and Western part of Bali Island) each of 10 stations and offshore (Bali Strait) location with 9 stations. The offshore consist of two locations, the surface and thermocline water column.

2.2. Samples collection

Data were collected at 9 stations in offshore area by taking samples of plankton using plankton net and water samples using a CTD (Conductivity Temperature Depth) that has 12 tubes. At 10 nearshore stations, plankton and water samples were taken directly on the surface.

Plankton at off shore stations was taken by plankton net hauling from 10 meters depth up to the surface, whereas water samples were taken by using a tube on the CTD at 10 meters depth. Plankton at in shore stations was taken by taking water directly from the surface and then it was filtered with plankton net. Plankton sampling at thermocline water column was taken by tube on CTD. When the CTD was lowered, CTD measured the water column temperature of each depth. The depth of thermocline was determined from the temperature-depth profile.

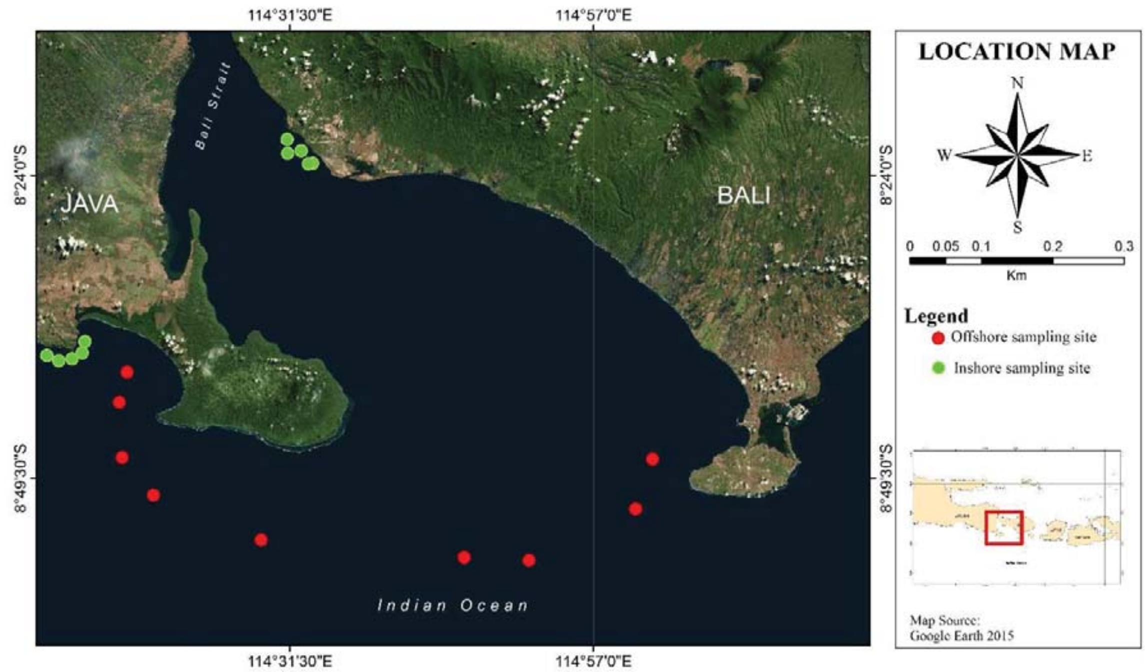


Figure1. Research sites in connected waters of Bali Strait

2.3. Data analysis

Plankton abundance was observed using a Sedgewick Rafter Counting Chamber (SRC). The morphological identification of phytoplankton was defined by using reference book [7] [8] [9] [10]. Plankton abundance was expressed in individuals per m^3 with by the following formula [11]:

$$N = n \times \frac{V_t}{V_{src}} \times \frac{A_{src}}{A_a} \times \frac{1}{V_d}$$

Description:

N	= Abundance of phytoplankton (cell/m^3)
n	= Organisms observed (cell)
V_d	= Volume of filtered water (m^3)
V_t	= Volume of water filtered (ml)
V_{src}	= Volume of the SRC (1 ml)
A_{src}	= Cross-sectional area of SRC
Aa	= Area of observation

The observation of the phytoplankton abundance was carried out on the water samples. Diversity of plankton was analysed employing the species richness of the plankton. Diversity α is the number of species found in a locality (stations), diversity β is the difference in diversity between localities were observed (intra-space/location), and the diversity of γ is the total diversity of species contained in the scope of a wider (regional) [12].

$$\beta_{cc} = [(b+c)/(a+b+c)]\text{, or}$$
$$\beta_{cc} = \beta_3 + \beta_{rich}$$
$$\beta_{-3} = 2\times[(\min(b,c)/(a+b+c)]$$
$$\beta_{rich} = [(b-c)/(a+b+c)]$$

Description:

β_{cc} = Difference in diversity between localities
β_3 = Turnover between localities
β_{rich} = Difference in the proportion of intra-space diversity (*nestedness*)
a = Number of species that can be found in both localities
b = Number of species that are found only in one locality
c = Number of species found only in the two locality

Determination diversity α, β, and γ in this study was to describe the diversity of each location or locality (α), intra-space diversity (β), and the total diversity of plankton species found in this research (γ). Accordingly, local diversity (α_i) is a value richness of plankton at each station, while the total diversity (γ) are the richness of the overall value of stations observed. Meanwhile, the difference in intra-space diversity (β) is obtained based on the results of a particular calculation. Determination of intra-space diversity can be made by Jaccard calculation formula which has two components, namely β_3 and β_{rich}. Components of β_3 are the difference in the proportion of intra-space diversity (nestedness), while the turnover kind intra-space diversity β_{rich} is being compared (turnover) [13]. Here is the formula for Jaccard and its components.

3. Result and Discussion

3.1 Abundance and number of species

The result showed that composition of phytoplankton based on number of species in the waters of the Bali Strait consists of three classes, i.e. Bacillariophyceae, Dinophyceae, and Cyanophyceae. Composition of phytoplankton based on group is presented in (Figure 2). Group of Bacillariophyceae had the highest composition in offshore location with 73-85% and 71-78% for nearshore location. Phytoplankton was dominated by Bacillariophyceae. Bacillariophyceae class (diatoms) was mostly found in this research. Generally, phytoplankton in the sea is composed by diatom species (Bacillariophyceae), followed by dinoflagellates (Dinophyceae) and blue green algae (Cyanophyceae) [14].

Total abundance of phytoplankton in each location was showed in Figure 3. Total abundance ranged from 151476-4285209 cell/m^3. Location that had the highest abundance of phytoplankton was surface, while the lowest was thermocline. Based on abundance, the highest phytoplankton composition was also obtained for Bacillariophyceae. The common phytoplankton in the ocean that is usually found in large abundance consists of two groups that dominate i.e diatoms (class Bacillariophyceae) and dinoflagellates [15] [16].

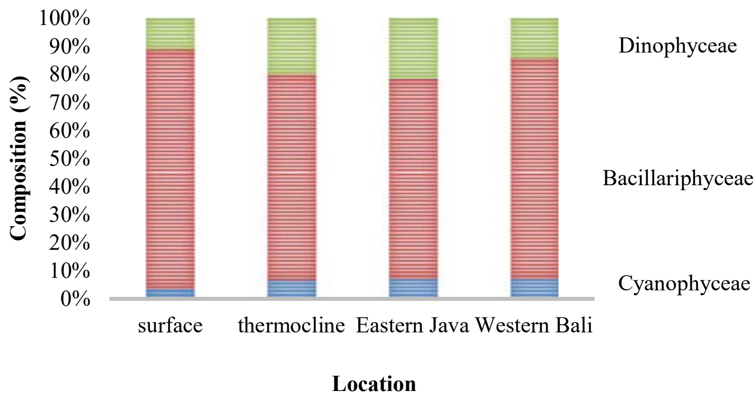


Figure 2. Composition of phytoplankton

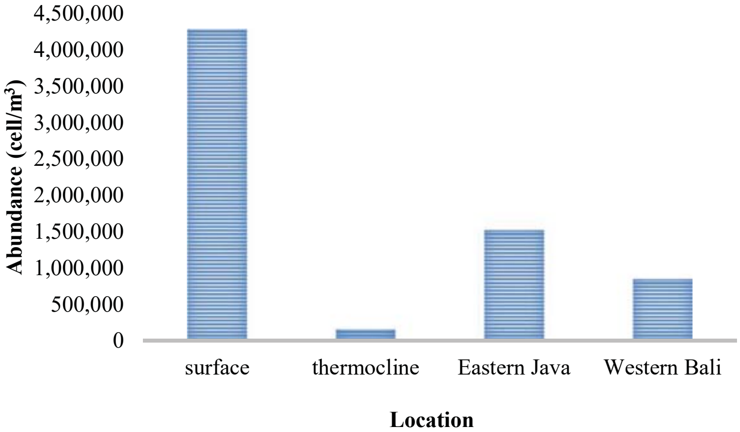


Figure 3. Total abundance of phytoplankton

Zooplankton community in waters of Bali Strait consisted of various zooplankton populations. A total of 5 groups of zooplankton had identified during research period. Based on composition number of zooplankton species (Figure 4), it was known that zooplankton of Crustacea group had the highest number of species in all locations (38 to 45%). Crustacea is the dominant zooplankton found in the sea [14].

Abundance of zooplankton during the study is presented in Figure 5. The abundance ranged from 33098-1413069 ind/m3. Location that had the highest abundance of zooplankton was surface, while the lowest was thermocline. This pattern is similar with the pattern of phytoplankton abundance. Zooplankton abundance is influenced by the abundance of phytoplankton [17].

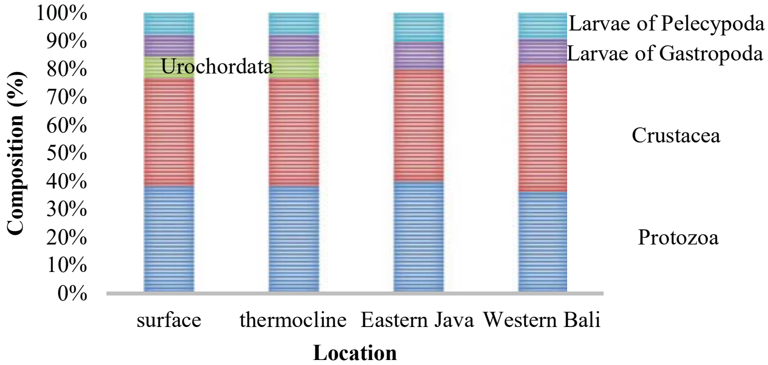


Figure 4. Composition of zooplankton

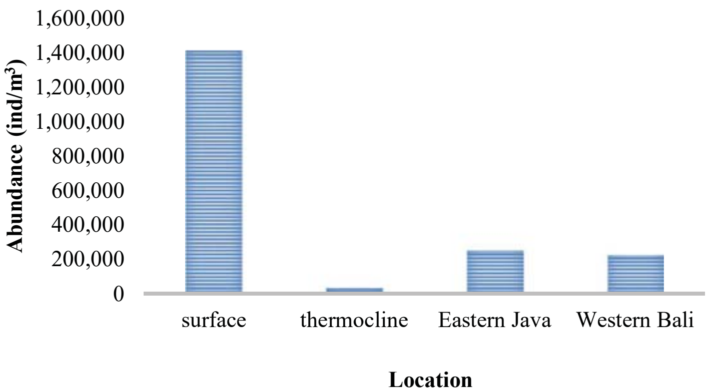
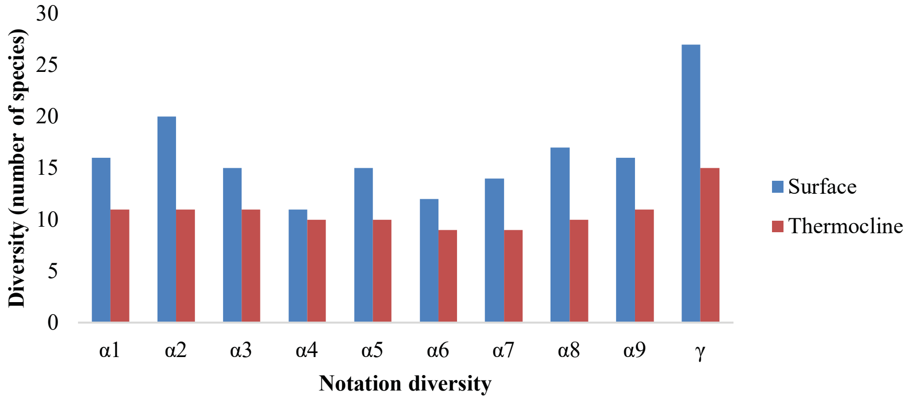
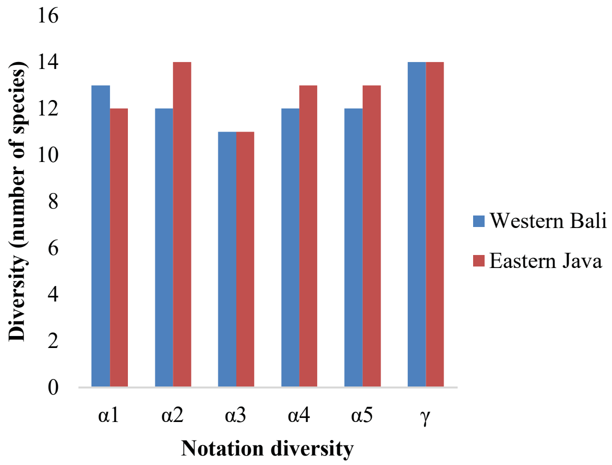


Figure 5. Total abundance of zooplankton

3.2 Local diversity (α), intra-space diversity (β), and regional (total) diversity (γ) phytoplankton
Local diversity (α) and total diversity (γ) of phytoplankton in offshore and nearshore locations (Figure 6a and 6b) showed that the highest diversity was in the α2 for surface offshore (20 genera) and α2 for Eastern Java nearshore (14 genera). Total phytoplankton diversity (γ) in the offshore was 27 and 15 genera. Meanwhile, there were 14 genera in both nearshore locations, Western Bali and Eastern Java. Total diversity (γ) in surface and thermocline location, Eastern Java, and Western Bali are not much different from the phytoplankton species that found in every station (locality). It indicated that phytoplankton species found in every station was almost similar.



(a)



(b)

Figure 6. α and γ diversity of phytoplankton

Table 1 showed the intra-space (β) diversity of phytoplankton in the offshore waters between surface and thermocline location. It showed that the difference in total diversity (β_{cc}) was high during research period (value was close to 1). Diversity of phytoplankton (number of species) on surface location was higher than thermocline location. Generally, the total diversity difference (β_{cc}) between surface location was more affected by the high value of β_3 (turnover) than the value of β_{rich} (nestedness). High value of β_3 in waters indicates that any phytoplankton species in the surface location different from phytoplankton species in the thermocline. When a high value of β_{cc} is affected by β_3, turnover species between localities might occur. Instead, when a high value of β_{cc} is affected by

β_{rich}, phytoplankton in locality that has lower diversity is a part of phytoplankton in locality that has higher diversity, for example on α_{S2} & α_{T2} and α_{S8} & α_{T8}.

The intra-space (β) diversity of zooplankton in the nearshore waters between Eastern Java and Western Bali location was showed in Table 2. Generally, the difference in total diversity (β_{cc}) in both locations tends to have a low value, which means phytoplankton in both locations was almost similar.

Table 1. Intra-space (β) diversity of phytoplankton in the offshore waters

Diversity β	Station								
	α_{S1} & α_{T1}	α_{S2} & α_{T2}	α_{S3} & α_{T3}	α_{S4} & α_{T4}	α_{S5} & α_{T5}	α_{S6} & α_{T6}	α_{S7} & α_{T7}	α_{S8} & α_{T8}	α_{S9} & α_{T9}
β_{cc}	0,714	0,591	0,579	0,765	0,684	0,833	0,647	0,684	0,650
β_3	0,476	0,182	0,421	0,706	0,421	0,667	0,353	0,211	0,400
βrich	0,238	0,409	0,158	0,059	0,263	0,167	0,294	0,474	0,250

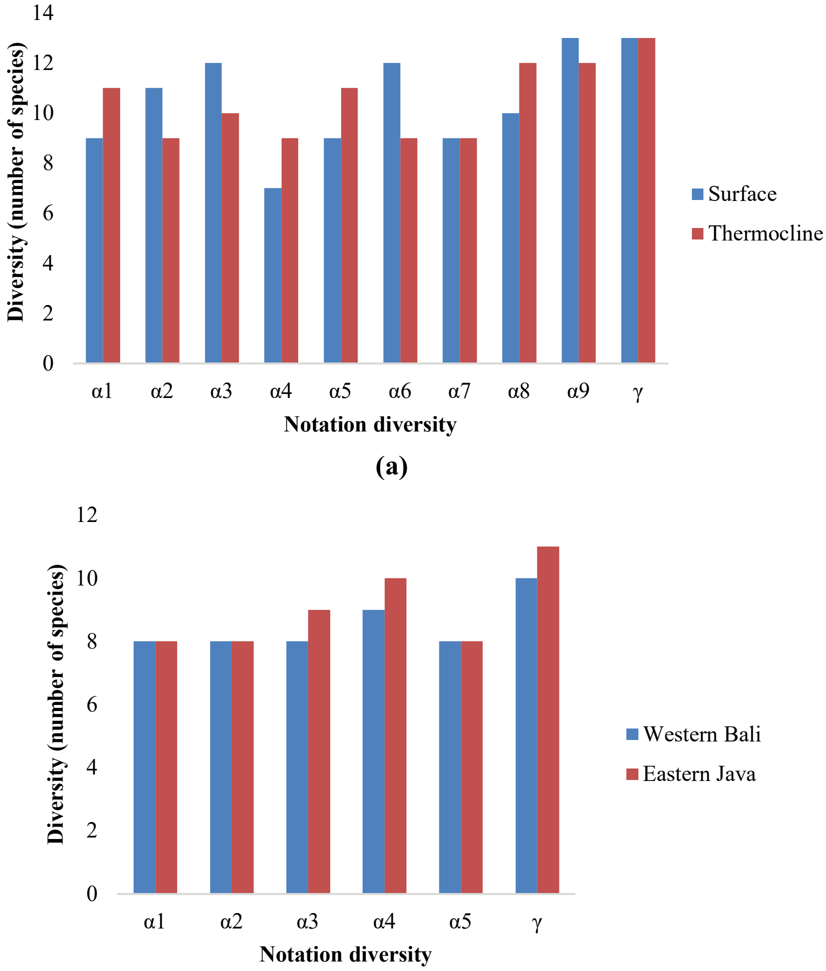
Table 2. Intra-space (β) diversity of phytoplankton in the inshore waters

Diversity β	Station				
	α_{WB1} & α_{EJ1}	α_{WB2} & α_{EJ2}	α_{WB3} & α_{EJ3}	α_{WB4} & α_{EJ4}	α_{WB5} & α_{EJ5}
β_{cc}	0,214	0,267	0,429	0,214	0,214
β_3	0,143	0,133	0,429	0,143	0,143
βrich	0,071	0,133	0,000	0,071	0,071

3.3. Local diversity (α), intra-space diversity (β), and regional (total) diversity (γ) zooplankton

Alpha (α) and gamma (γ) diversity of zooplankton in offshore and nearshore locations (Figure 7a and 7b) showed that the highest diversity was in the α9 for surface offshore (13 genera) and α4 for Eastern Java nearshore (14 genera). Total phytoplankton diversity (γ) in offshore location was 27 and 15 genera. Meanwhile, there were 14 genera in both nearshore locations, Western Bali and Eastern Java. Total diversity (γ) in surface and thermocline location, Eastern Java, and Western Bali were not much different from zooplankton that was found in every station (locality). It indicated that species zooplankton found in every station was almost the same.

Table 3 showed the intra-space (β) diversity of zooplankton in the offshore waters between surface and thermocline location. It showed that the difference in total diversity (β_{cc}) was low during research period (value was close to 0). Difference in total diversity (β_{cc}) of zooplankton in offshore waters was more affected by the value of β_{rich}. It means zooplankton in locality that has lower diversity is part of zooplankton in locality that has higher diversity, like in α_{S3} & α_{T3}, α_{S4} & α_{T4}, and α_{S6} & α_{T6}. Similar to zooplankton in offshore waters, the difference in total diversity (β_{cc}) in nearshore waters was generally low. The value of β_{cc} is affected by β_3, which means turnover species between localities might occurr.



(b)

Figure 7. α and γ diversity of zooplankton

Tabel 3. Intra-space (β) diversity of zooplankton in the offshore waters

Diversity β	Station								
	α_{S1} & α_{T1}	α_{S2} & α_{T2}	α_{S3} & α_{T3}	α_{S4} & α_{T4}	α_{S5} & α_{T5}	α_{S6} & α_{T6}	α_{S7} & α_{T7}	α_{S8} & α_{T8}	α_{S9}& α_{T9}
$\boldsymbol{\beta_{cc}}$	0,333	0,333	0,167	0,222	0,462	0,385	0,364	0,308	0,077
$\boldsymbol{\beta_{3}}$	0,167	0,167	0,000	0,000	0,308	0,154	0,364	0,154	0,000
$\boldsymbol{\beta_{rich}}$	0,167	0,167	0,167	0,222	0,154	0,231	0,000	0,154	0,077

Table 4. Intra-space (β) diversity of zooplankton in the inshore waters

Diversity β	Station				
	α_{WB1} & α_{EJ1}	α_{WB2} & α_{EJ2}	α_{WB3} & α_{EJ3}	α_{WB4} & α_{EJ4}	α_{WB5} & α_{EJ5}
$\boldsymbol{\beta_{cc}}$	0,400	0,222	0,455	0,100	0,222
$\boldsymbol{\beta_{3}}$	0,400	0,222	0,364	0,000	0,222
βrich	0,000	0,000	0,091	0,100	0,000

As a whole, there were found 27 species of phytoplankton and 13 kinds of zooplankton, as each of γ diversity. At the surface water, all species of phytoplankton were found in offshore stations, and 14 of them were found in both nearshore locations. All 13 kinds of zooplankton were also found in offshore stations, and 10 to 11 of them were found in nearshore locations.

4. Conclusion

Phytoplankton and zooplankton were well distributed at the surface, but showed as spesific distribution at thermocline layer, especially for phytoplankton.

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