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PRIMARY PRODUCTIVITY OF REHABILITATED MANGROVE ECOSYSTEMS IN BEEJAY MANGROVE RESORT PROBOLINGGO

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Abstract

Mangroves in the BeeJay Bakau Resort Probolinggo area are a rehabilitation area that has become an ecotourism area. The present study was performed in December 2020 to study the contribution of the mangrove ecosystem to primary productivity. Sediment, water, and plankton samples were taken at three stations in the same location as mangrove vegetation data collection. Variations in environmental characteristics between research stations were analyzed using principal component analysis (PCA) and multiple linear regression. The results show that the concentration of available P ranged from 37.00-69.32mg/kg, the concentration of C-organic ranged from 1.30-2.61% and the concentration of N-total ranged from 2.57-4.80%. Meanwhile, in water, the concentration of chlorophyll-A, nitrate and orthophosphate was between 2.67 – 9.94g/L, respectively; 0.11- 0.373mg/L; 0.036 – 2.79mg/L. Identification of phytoplankton in the waters of the BJBR ecosystem, there are three classes of phytoplankton. The highest abundance is Bacillariophyceae. The zooplankton found consisted of 7 classes, with the highest abundance is Crustacea. The concentration of available P and total N in the study area is high, which is assumed to contribute to nitrate and phosphate concentration in the waters. Based on the linear regression results, nitrate and phosphate have a strong relationship with chlorophyll-A, an indicator of primary productivity.

***Keywords**: BeeJay Bakau Resort; Probolinggo; Mangrove; Primary productivity; Chlorophyll-A; Plankton*

Introduction

The mangrove ecosystem combines several tropical and sub-tropical ocean and land ecosystems on sloping beaches protected from the sea's waves [1]. Mangrove is an ecosystem with a specific community structure consisting of species composition, growth structure, and productivity and has an essential function as a habitat for plankton and other organisms. The mangrove sustainability indicator can use the density and abundance of organisms [2]. The basic indicator to show mangrove conservation is mangrove diversity [3], vegetation structure, water quality assessment [4], ecological stability [5], mangrove litter [6], dan mangrove function [7]. Mangroves are also important for the survival of aquatic biota. The mangrove ecosystems are essential for spawning grounds, nursery grounds, and feeding grounds.

The productivity of an aquatic ecosystem can be supported by the presence of nutrients and chlorophyll-A in the waters [8]. Nutrients in Beejay Bakau Resort Probolinggo are caused by the decomposition of litter in the mangroves themselves, apart from rivers that carry

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domestic waste into the waters because the mangroves here are located close to residential areas and ponds. The decomposition process that occurs in the mangrove will produce nutrients such as nitrate and phosphate.

Classification of water productivity is by calculating the concentration of chlorophyll-A, phosphate, and nitrate [9]. Nitrates and phosphates are essential nutrients for the growth of plankton in mangrove waters [10]. In addition to nitrate and phosphate, chlorophyll-A is also quite substantial on water productivity because chlorophyll-A is the most abundant type of chlorophyll in phytoplankton.

The productivity of the mangrove ecosystem is related to the primary productivity of the waters, which is very closely associated with plankton [10]. The higher the supply of nutrients, the higher the primary productivity of plankton. If the primary productivity of plankton is low, the carrying capacity of the waters is also low [11, 12]. The primary productivity of waters is produced by the photosynthesis process carried out by plankton. The amount of plankton in the waters is caused by the environmental factors of mangrove waters which significantly affect the life of aquatic biota.

As a coastal area, Probolinggo City has a mangrove area of 90 hectares, located close to the Coastal Fishing Port, Mangunharjo Village, Mayangan Probolinggo District, Probolinggo City. The high human population density and rapid economic growth around the mangrove ecosystem make the coastal environment vulnerable to anthropogenic stress factors. The mangrove ecosystem in this area was previously a domestic waste disposal area with highly degraded mangrove conditions. Then this mangrove area was managed and rehabilitated into a tourist attraction under the name Beejay Bakau Resort (BJBR). A balanced ecosystem will be suitable for water productivity and support the stock of fish resources in the Probolinggo Waters.

It is essential to know information about chlorophyll-A, nutrients (phosphate and nitrate), and plankton which are helpful as productivity indicators in the Beejay Bakau Resort's mangrove waters ecosystem, which is the background of this research. This research is expected to reveal the concentration of chlorophyll-A, nitrate, phosphate, and plankton in mangrove ecosystems that benefit the survival of mangrove aquatic biota.

Materials and Method

We conducted this research in December 2020. A sampling at three stations was carried out in the BeeJay Bakau Resort area, Probolinggo (Fig. 1).

Station one has rehabilitated mangroves nearest the tourist area entrance (substations 1.1, 1.2, 1.3). Station two is a combination of rehabilitated and natural mangroves at the center of the tourist area with many tourist buildings (substations 2.1, 2.2, 2.3). Station three is a natural mangroves area. The farthest from the tourist area but close to the pond (substations 3.1, 3.2, 3.3). Laboratory analysis was carried out at the Water Productivity and Environment Laboratory, MSP Department, Faculty of Fisheries and Marine Sciences, IPB University.

Water and Sediment Sampling

Plankton samples were taken at high and low tide at each station. Samples were taken on the water's surface using a 5L bucket of 50L, then filtered using a plankton net with a mesh size of 25m. We put the remaining filtered water into a sample bottle with a volume of 40ml and adding 2-3 drops of 4% Lugol. Water samples for chlorophyll-A were taken from the water surface as much as 1000mL, then filtered using cellulose filter paper [13].

Sediment sampling was carried out at each sub-station. Sediment samples were taken using a sediment core inserted into the soil at a depth of 5cm. Sediment samples were analyzed in the laboratory to determine C-organic, N-total, and P-available and sediment fraction content. Water samples were taken three times at high tide and low tide. Samples were taken at the same depth of 50cm from the surface, stored in a cool box, and then analyzed in the laboratory.

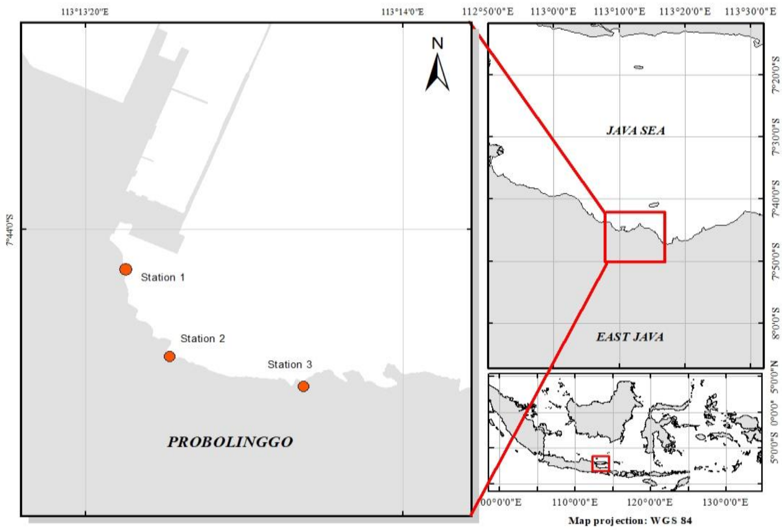

Fig. 1. Map of research location

Analysis of Nutrient Content in Water and Sediment

The C-organic sediment content was analyzed using the Walkey-Black method, the total N content was analyzed using the Kjeldahl method, and the analysis of available P using the Bray I method. The concentration of nitrate in the water was measured using the reduction column method. Phosphate concentration was measured using the ascorbic acid method [14].

Chlorophyll and Plankton Analysis

The preserved samples were then counted using an electron microscope and a 1.0mL Sedgewick Rafter Cell. Identification of plankton based on identification book by *Perry* [15] and *Conway* [16]. The abundance of plankton was calculated per observation station using the method *Lackey drop microtransect counting* [14] as follows:

$$N = \frac{1}{Vd} \times \frac{Vt}{Vs} \times n \qquad (1)$$

where: N is the number of individuals per (m^3); Vd is the volume of filtered water (m^3); Vt. is the volume of filtered water (ml); Vs. is the volume of water in the Sedgewick Rafter Cell (ml); n is the amount of phytoplankton.

Analysis of chlorophyll-A samples was carried out based on APHA [14], using the spectrophotometric method and 90% acetone solution. The wavelengths used in the spectrophotometer measurements include 630, 647, 664 and 750nm. Chlorophyll-A is calculated using the equation:

$$\textit{Chlorophyll-A} = 11.85\ (\lambda 664) - 1.54\ (\lambda 647) - 0.008\ (\lambda 630) \qquad (2)$$

$$\textit{Concentration of Chlorophyll-A} = \textit{Ch-a} \times \frac{v}{V} \qquad (3)$$

where: 664 is the absorbance at the wavelength of 664nm; 645 is the absorbance at the wavelength of 645nm; 630 is the absorbance at the wavelength of 630nm; v is the extract volume (dm^3); V is the sample volume (m^3).

Data Analysis

Variable analysis at each station uses principal component analysis (PCA) to see the relationship between variables and produces a graphical representation [6, 17]. This analysis uses the following equation:

$$d^2(i,i') = \sum_{j=1}^{p} (X_{ij} - X_{i'j})^2 \quad (4)$$

where: i are two rows, and j is the column index (varies from 1 top). The smaller the Euclidean distance between the substations, the more similar the environmental characteristics between the substations are, and vice versa.

Then proceed with multiple linear regression analysis, determining the influence or linear relationship between chlorophyll-A with phosphate and nitrate [18]. The model generated by multiple linear regression is:

$$Y_i = \beta_0 + \beta_0 X_{ij} + \cdots + \beta_{p-1} X_{ip-1} + \varepsilon_i \quad (5)$$

where: Y_i is the dependent variable for the 1st observation, β_0, β_{p-1} are parameters, $X_{ij} X_{ip-1}$ is the independent variable, and ε_i is the residual value for the i^{th} observation.

Results and discussion

Environmental Characteristics of Mangrove Sediments

Overall, station 1 has a more acidic pH than the other two stations. Organic matter that is decomposed by anaerobic bacteria will produce organic acids. This result is in line with *Pawar's (2013)* [19] research wherein ecosystem conditions that get a lot of anthropogenic influences, the pH of the sediment will tend to be acidic (Table 1).

Table 1. Chemical characteristics of the sediment substrate at the research site

Sub-station	pH	C-Organic (%)	Available-P (mg/kg)	N-Total (%)	Redox Potential (mV)	Sand	Silt	Clay
1.1	7.26	2.32	62.06	4.30	-40.7	11.90	12.29	75.81
1.2	6.86	2.51	66.76	4.63	-12.2	11.58	11.55	76.87
1.3	6.89	2.46	65.62	4.55	-11.4	9.98	9.68	80.34
2.1	7.44	1.84	50.24	3.48	-46.8	16.57	9.98	73.45
2.2	7.25	2.38	63.48	4.40	-31.5	16.30	10.05	73.65
2.3	7.24	2.61	69.32	4.80	-30.7	17.84	11.15	71.01
3.1	7.55	1.30	37.00	2.57	-52.1	15.28	11.20	73.52
3.2	7.07	2.37	63.20	4.38	-23.3	15.27	12.48	72.25
3.3	7.47	2.01	54.37	3.77	-45.6	16.12	11.32	72.56

The redox potential (Eh) shows a trend in substation 1, lower than the other substations (Table 1). The Eh value of all sediment samples was negative. According to *Pan et al.* [20], this shows the anoxic condition of mangrove sediments. The concentrations of available P, organic C, and total N at the study site were generally higher than the study conducted by *Nursin et al.* [21]. The mangroves density in the research location is usually classified as dense.

Station 1 has a sedimentary texture of clay, while those with a sandy loam sediment texture are stations 2 and 3. The binding of particles by mangrove roots causes the particles to settle into the sediment. High percentages of clay and silt are commonly found in mangrove species such as *Rhizophora* sp. and *A. marina* [22, 23].

Based on *PCA* (Fig. 2), It was seen that the low sediment pH correlated with the content of available P, organic C, and N-total, which tended to be higher. The low pH in mangrove sediments is due to the mineralization process of organic matter [24]. The high porosity of the sediment causes CNP nutrients that tend to be low on sandy substrates. The organic matter content in the muddy substrate is generally higher than the organic matter content in the sand substrate. Sludge porosity causes organic matter to be retained. Typically, the substrate in the mangrove area contains organic materials such as carbon, nitrogen, and phosphorus [25].

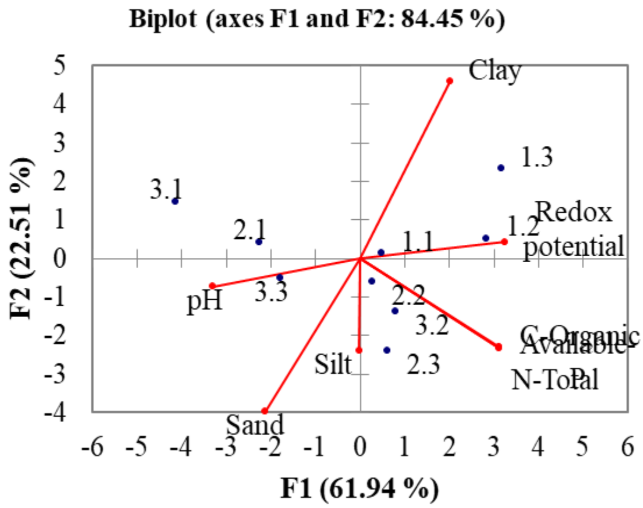

Fig. 1. Biplot Principal Component Analysis of sedimentary substrate characteristics of the mangrove ecosystem at the research site

Nutrients in Water Mangrove Ecosystems

During tidal and low tide conditions, station 1 had the highest concentration of chlorophyll-A and phosphate concentration. In contrast to nitrate, at high tide, the highest concentration is at station 1, but at low tide, the highest concentration is at station 2. Station 1 tends to have higher nitrate and phosphate concentrations than other high tide and low tide stations because this station is closed to the residents' waste disposal area containing organic matter. High nutrients result in high concentrations of chlorophyll-A [26]. Chlorophyll-A can be used as a biomarker in aquatic ecosystems [27] and guide environmental protection and fishing area mechanisms. The abundance of chlorophyll-A (Table 2) indicates a eutrophication process that affects the dynamics of marine biogeochemical ecosystems and can predict future ecosystem conditions following the reaction of increasing the influence of human activities on the marine environment [28].

Table 2. The concentration of chlorophyll-A, nitrate and phosphate

Station	Condition	Chlorophyll - A (μg/L)	Nitrate (NO_3-N) (mg/L)	Phosphate (PO_4-P)$^+$ (mg/L)
1	High Tide	4.877	0.125	0.122
2		2.672	0.088	0.058
3		4.832	0.112	0.036
1	Low Tide	9.945	0.332	0.279
2		7.044	0.373	0.219
3		5.998	0.224	0.177

In general, station 1 has the highest trend of chlorophyll-A, nitrate, and phosphate concentrations which is assumed that waste disposal and the presence of massive ecotourism activities in the area around station 1 contribute to the increase in nutrient levels in this area. Station 3, the least affected by human activities, has the lowest phosphate concentration, but nitrate concentration does not follow this trend. However, nutrient and chlorophyll concentrations were generally higher at low tide, which was also reported in the study of *Bubu-Davies and Ugwumba* [29]. *Li et al.* [30] said that the increase in water containing nutrients N and P was mainly caused by human activities. Phosphate and nitrate are essential to support the growth and life stages of phytoplankton. The high potential of nutrients in aquatic ecosystems will increase the density of plankton [2]. Station 2 near the mainland has the highest nitrate content. It is suspected that the decomposition of sediments and organic compounds derived from the bodies of dead biota can affect the high nitrate content in mangrove waters [31].

Plankton in Mangrove Ecosystem Waters

Based on the results of phytoplankton identification from all observation stations in the waters of the BJBR ecosystem, there are three classes of phytoplankton, namely Bacillariophyceae (26 genera), Cyanophyceae (1 genus), and Dinophyceae (4 genera). Based on the results of zooplankton identification, it is known that the composition of the zooplankton species found consisted of groups of Protozoa (1 genus), Crustacea (7 genera, 1 stadia nauplius), Urochordata (1 genus), Pelecypoda (larvae), Gastropods (larvae), Nematodes, Polychaeta, and Coelenterates (Fig. 3).

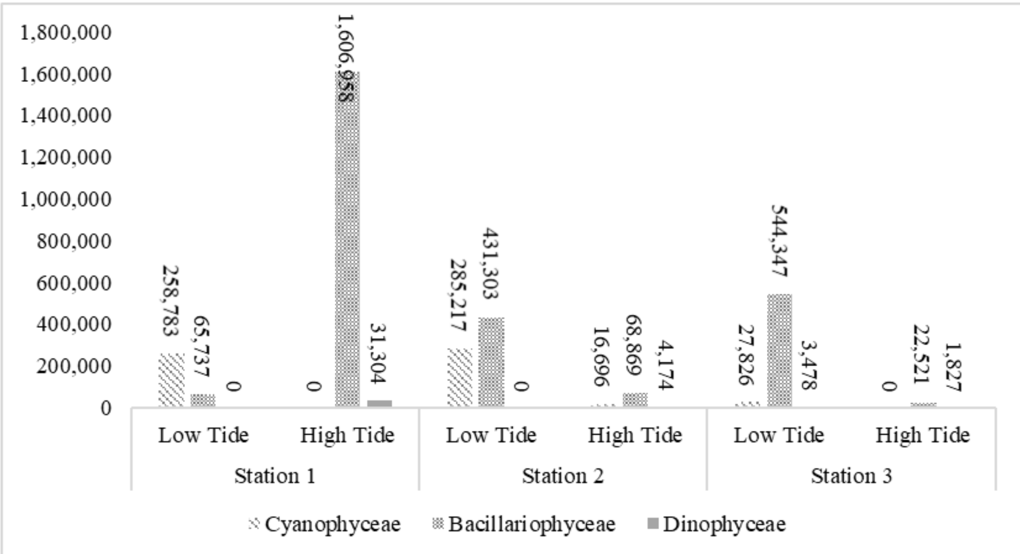

Fig. 3. The abundance of phytoplankton (cell/m^3) for each class at each station during high and low tide conditions

The abundance of phytoplankton at each station showed that stations 1, 2 and 3 at low tide, respectively, had the highest abundance for Cyanophyceae, Bacillariophyceae, and Dinophyceae. While at high tide, the three stations had the highest abundance in the Bacillariophyceae class (Fig. 3). The abundance of zooplankton at each station shows the highest abundance for the Crustaceae at all stations at low tide. Similarly, at high tide, the class Crustacea was found to have the highest abundance at all stations (Fig. 4).

The abundance of phytoplankton at station 1 is relatively higher than in station 2 and station 3. Stations 2 and 3 have a relatively low abundance of phytoplankton, presumably influenced by the physical conditions of the less supportive waters for phytoplankton growth. It is different from station 1 where the high abundance of plankton is related to the high nutrient content at station 1 compared to other stations. Many of the Bacillariophyceae classes are found due to the cosmopolitan nature of organisms in this class and have high tolerance and adaptability to changes in the marine environment [32]. According to *Nybakken* [33], the class of Bacillariophyceae can multiply even in conditions of low light and nutrients. It is also because this type of phytoplankton can adapt well to regenerate and reproduce in more significant numbers than other types of phytoplankton. This type of plankton is also the most resistant to environmental changes by tidal influences.

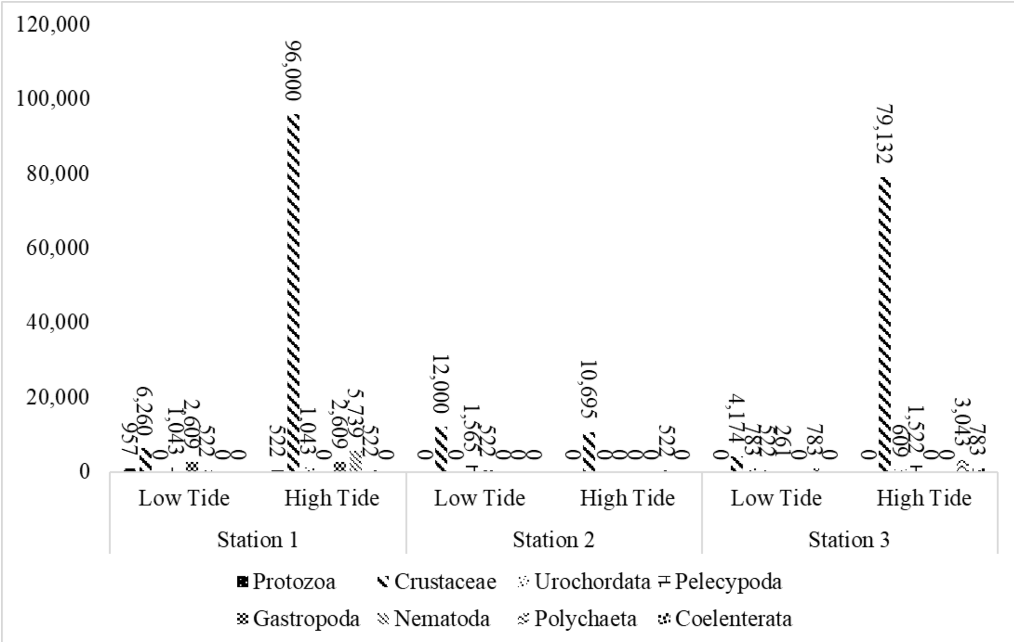

Fig. 4. The abundance of zooplankton (individual/m^3) for each class at each station during high and low tide conditions

Some Bacillariophyceae found in the mangrove ecosystem of Beejay Bakau Resort are species that can be found in freshwater. The mangrove ecosystem here is traversed by rivers that carry freshwater to the open sea. The genus of the Bacillariophyceae class that looks dominant is different for each station. But the most clearly seen dominant are the genera *Navicula*, *Nitzschia*, and *Skeletonema*. It is in line with *Madhavi et al.* [34] and *Satheesh and Wesley* [35], which states that the three types of phytoplankton are most often found in coastal and estuary areas.

Like phytoplankton, the abundance of zooplankton at Station 1 is relatively higher than in Station 2 and 3. It is suggested that the availability of food (phytoplankton) for zooplankton growth is sufficient. The availability of phytoplankton as food supports the density of zooplankton in the waters. The higher density of zooplankton occurred due to the influence of phytoplankton, which is the main food of zooplankton. Phytoplankton has a role as a producer, a source of energy for the life of other organisms [36].

Link Between Nutrients and Productivity

The estimation results using multiple linear regression showed that nitrate and phosphate significantly affected the chlorophyll-A concentration with an adjusted R square value of 0.686 (Fig. 5). It shows that about 68.6 percent of the variables can explain the effect on chlorophyll-A concentration, and the rest is explained by other variables that are not studied, such as water brightness. It appears that the pattern of the relationship is directly proportional to the positive value of the slope. The regression model showed significant results (F = 37.22, P = 0.007).

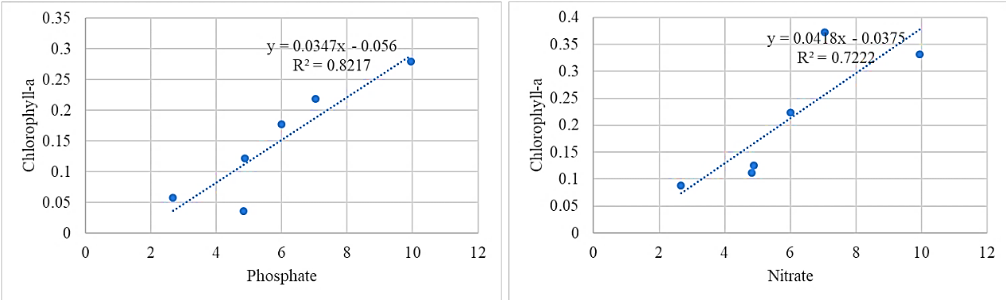

Fig. 5. Linear regression between chlorophyll-A with nitrate and phosphate

Based on the analysis of the relationship between the concentration of nitrate and phosphate to chlorophyll-A. The chlorophyll-A in the waters increases along with the increase in the nitrate and phosphate concentrations. It is in line with the research conducted by *Ayuningsih et al.* [37], which showed that nitrate and phosphate have a strong correlation coefficient with chlorophyll-A. Nitrates and phosphates are essential nutrients for higher plants and algae [38]. Chlorophyll-A is the most abundant type of chlorophyll in phytoplankton [8], so that indirectly the picture of the relationship between nutrients and chlorophyll-A is a picture of the relationship between nutrients and phytoplankton. Water productivity is a function of excess nutrient input load and chlorophyll. Nutrients in the BJBR ecosystem are caused by litter decay. The decomposition process will produce nutrients such as nitrate and phosphate, which are needed by phytoplankton.

The results of PCA analysis on phytoplankton, nutrients, and stations (Fig. 6) show a concentration on the main axis, where each parameter contributes 93.28% of the total variance, where the F1 axis explains 60.53%, and F2 presents 32.75%. A high abundance of Cyanophiceae characterized the high tide at stations 1 and 3, and station 2 for the high abundance of Dinophyceae and Bacillariophyceae. The high levels of nutrients and chlorophyll-A indicate all stations at low tide.

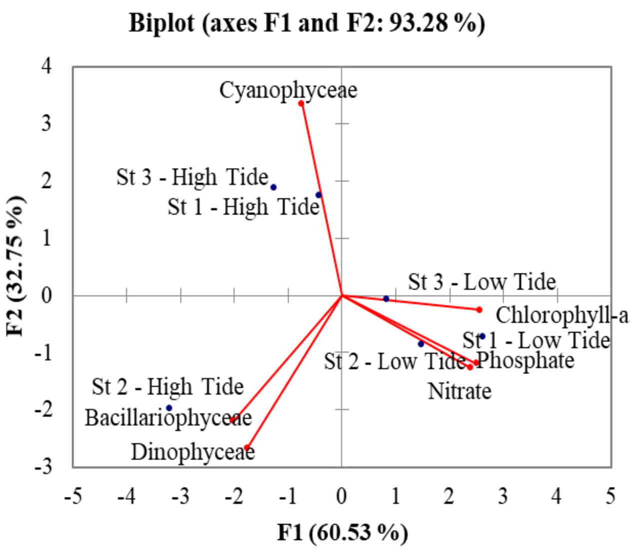

Fig. 6. The results of the principal component analysis (PCA) characteristics of phytoplankton stations at the research site on axis 1 (F1) and axis 2 (F2)

We found the Bacillariophyceae class in almost all stations, both at high and low tide. The Bacillariophyceae can adapt to various environmental conditions compared to other classes. The Bacillariophyceae class adapts well to environmental conditions, has a high tolerance and adaptability so that this class is cosmopolitan [39]. This situation is often found in Indonesian and territorial waters in other areas [40, 41].

The results of the analysis of the main components of zooplankton at each station (Fig. 7) show a concentration on the main axis, where each parameter contributes 75.99% of the total variance, where the F1 axis explains 40.68%, and F2 explains 35,31%. A high abundance of pelecypods and nematodes characterizes station 2 at low tide. Station 3 at low tide is characterized by a high abundance of Polychaeta and Coelenterata.

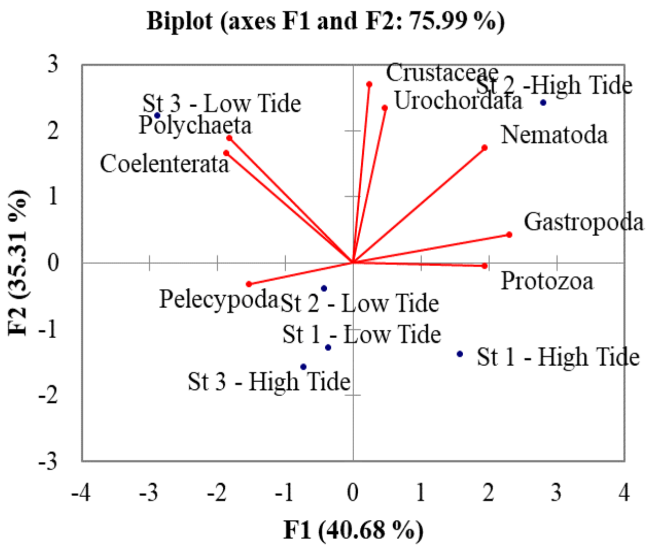

Fig. 7. Results of principal component analysis (PCA) characteristics of zooplankton stations at the study site on axis 1 (F1) and axis 2 (F2)

The abundance of Polychaeta and coelenterates at station 3 at low tide was in line with the high chlorophyll-A levels. Station 2 at high tide nematode, crustacean, and Urochordata abundance was associated with high Bacillariophyceae and Dinophyceae. *Trichodesmium* sp. is the most commonly found of the class Dinophceae. *Trichodesmium* sp. is a food source for zooplankton such as nematodes, crustaceans, and Urochordata [42]. Bacillariophyceae class is mainly found in *Navicula* sp., a key species in the food chain of aquatic ecosystems and is a staple food for many marine species [43].

Conclusions

The mangrove ecosystem at Beejay Bakau Resort shows that overall, the abundance of plankton seems to be related to the export of nutrients from sediments that enter the waters. The high concentration of nutrients in the sediment causes the increase of nutrients concentration in the waters. Bacillariophyceae dominates phytoplankton in the waters, while Crustaceae dominates zooplankton. The concentration of nitrate and phosphate in the waters strongly correlates with chlorophyll-A as an indicator of primary productivity. Further studies of other factors affecting primary productivity across the region are needed to document environmental changes over time.

Acknowledgments

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