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The Distribution of Phytoplankton in Mangroves, Seagrass Beds, and Coral Reefs Ecosystem in West Sekotong Coastal, West Lombok

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Abstract: The West Sekotong coastal area, which includes mangrove, seagrass, and coral reef ecosystems, is rich in marine biota, particularly phytoplankton communities. These ecosystems have been designated as conservation areas; however, increasing exploitation and disturbances in the region have impacted the presence and distribution of phytoplankton. This study aimed to assess the distribution, abundance, and species diversity of phytoplankton across these three ecosystems. Using purposive sampling, phytoplankton communities were identified microscopically, revealing a total of 742 phytoplankton cells, with 264 cells in the mangrove, 258 cells in seagrass, and 220 cells in the coral reef ecosystems. The class *Bacillariophyceae* dominated across all ecosystems. Specific species dominance varied, with *Skeletonema costatum* prevailing in mangroves, *Nitzschia sigmoidhea* in seagrass, and *Coscinodiscus radiatus* in coral reefs. The highest similarity index (35.89%) was observed between mangrove and seagrass ecosystems, while the lowest (30.87%) occurred between mangrove and coral reefs. The species richness index (R) was high in all ecosystems, ranging from 6.45 to 10.26, and dominance indices were low, indicating a balanced community structure. Environmental parameters measured across the ecosystems showed no significant differences and met the quality standards for marine biota as per KEPMENLH No 51 2004.

Keywords: Coral reefs; Distribution; Mangrove; Phytoplankton; Seagrass; Sekotong

Introduction

West Nusa Tenggara (NTB) has a sea area spanning approximately 29,159.04 km^2 with a coastline extending over 2,333 km^2 (Direktorat Jenderal Penguatan Daya Saing Produk Kelautan dan Perikanan, 2017). This extensive marine coastal region positions NTB as an area teeming with diverse potential marine natural resources. Furthermore, NTB's marine expanse lies within the world-renowned Coral Triangle, celebrated for hosting the planet's most abundant tropical marine biodiversity (Pardede et al., 2014). Beyond that distinction, NTB serves as the gateway to the Wallacea region, recognized for its rich species diversity and high level of endemism (Khan, 2002). Consequently, many of NTB's coastal areas have been designated as national conservation areas, including the coastal regions of West Lombok Regency, with particular emphasis on the Sekotong sub-district (Dermawan et al., 2014). The coastal area of Sekotong has garnered significant attention, as it not only serves as a conservation area but also as a thriving marine tourism destination.

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Among the coastal areas in Sekotong, those situated in West Sekotong have garnered considerable attention due to their strategic location as transit points to the renowned tourist destinations of Gili Nanggu, Tangkong, and Sudak. The West Sekotong coastal region is characterized by a diverse range of ecosystems, including mangrove forests, seagrass beds, and coral reefs (Ilham et al., 2018). These ecosystems have been designated as conservation targets in accordance with West Lombok Regent Regulation No. 23/2014 (Dermawan et al., 2014). Within these ecosystems, a wealth of marine biota thrives, each playing a vital role in the coastal ecosystem (Putri et al., 2023). Among these, phytoplankton stands out as a particularly important biological resource in the sea.

Phytoplankton are microscopic organisms that live floating in the water column and play a crucial role in aquatic ecosystems as autotrophs (Rizki et al., 2023). According to Utami et al. (2021), phytoplankton can produce organic compounds by utilizing carbon energy from CO_2 and sunlight through the process called photosynthesis, making them primary producers within the aquatic ecosystem. Additionally, in the context of aquatic metabolic processes, phytoplankton act as nutrient recyclers (Oleza et al., 2017), contribute to regulating water temperature by shading and absorbing sunlight during photosynthetic activity (Alvarez et al., 2022), and as providers of dissolved oxygen to the water (Kumar et al., 2023). Furthermore, phytoplankton have wide-ranging applications, including their cultivation for use as a natural food source. Moreover, their presence can serve as a valuable indicator of water quality, aiding in the assessment of pollution levels in aquatic environments, thereby establishing their role as bioindicators (Zhang et al., 2021). Using pigment and morphological characteristics, Fritsch (1935, 1945) classified phytoplankton into 11 classes, Chlorophyceae, Cryptophyceae, Phaeophyceae, Rhodophyceae, Xanthophyceae, Dinophyceae, Bacillariophyceae, Chloromonadinae, Eugleniae, Chrysophyceae and Myxophyceae (Gireesh et al., 2015). The two major classes within the phytoplankton community Bacillariophyceae and Dinophyceae, assume pivotal roles in driving primary production and Contributing to the nutrient cycling within marine ecosystems (Lee et al., 2015).

Bacillariophyceae category encompasses over 200 genera, with more than 8,000 known and recorded species, this figure represents a fraction of the global, Bacillariophyceae species, estimated to range between 100,000 and 200,000, which play crucial role in marine ecosystems, contributing significantly to approximately 45% of the total primary production, in contrast, the Dinophyceae group comprises over 2,200 recorded and identified species (Guiry, 2012; Lee et al., 2015). Another significant component within marine ecosystems is phylum Cyanobacteria, comprising more than 3,000 recorded species out of the estimated global count of around 8,000 (Guiry, 2012; Nabout et al., 2013). Similar to Bacillariophyceae (diatoms) and Dinophyceae, Cyanobacteria play a crucial role in the ecosystem, primarily due to their capacity for nitrogen (N) fixation, phosphorus (P) storage, or iron (Fe) sequestration in certain species (Paerl & Otteh, 2013).

As cosmopolitan organisms, the presence of phytoplankton is spread in almost all parts of the water, both in mangrove forest, seagrass beds, and coral reefs. Within the water column, the abundance of phytoplankton exhibits dynamic changes in response to varying environmental conditions (Nybakken & Eidman, 1992). Currently, the coastal ecosystem areas in West Sekotong, including coral reef ecosystems, seagrass beds, and mangrove forests, have been widely exploited, which influences the presence of phytoplankton, which has a negative impact on water quality by diminishing sunlight penetration into the aquatic environment. The influx of anthropogenic activities in coastal areas, such as port-related operation and diverse tourist pursuit further disrupts the delicate balance of marine ecosystems and existence of marine biota. Given the rich marine biodiversity and associated challenges in NTB's coastal areas, effective marine resource management becomes paramount.

The availability of ecological data and comparative analysis of phytoplankton communities in mangrove, seagrass, and coral reef ecosystems within the West Sekotong coastal area, a region under increasing environmental stress, area represents the initial stride toward the efficient management of conservation areas and the flourishing marine tourism industry in NTB. While previous studies have focused on larger marine organisms, this research emphasizes the critical role of phytoplankton—both as primary producers and bioindicators of ecosystem health—within a conservation context. in the West Sekotong coastal area represents the initial stride toward the efficient management of conservation areas and the flourishing marine tourism industry in NTB. The results of this study are expected to complement the data on the distribution of marine biota in Lombok Island, particularly in conservation area such as the West Sekotong Coastal. However, it is equally important to understand the distribution of microorganisms, such as phytoplankton, which serve as primary producers in each ecosystem. Therefore, this research aimed to investigate phytoplankton distribution, abundance and diverse species in mangrove, seagrass and coral reef ecosystems in West Sekotong Coastal.

Method

Research Site and Sampling Method

This research was conducted in May-September 2021, applied a quantitative descriptive method. The determining of phytoplankton sampling locations followed a purposive sampling approach. The objects of this research encompassed both phytoplankton samples and seawater samples. Phytoplankton sampling was conducted within mangrove forest ecosystems, seagrass beds, and coral reefs in the coastal areas of West Sekotong, Sekotong District (including Batu Kumbu, Medang and Tanjung Kelor), West Lombok Regency. Identification and analysis of the collected sample took place in the biology laboratory, FMIPA, Mataram University. Phytoplankton sampling was executed across three different ecosystems, the coral reef ecosystem, a renowned snorkeling destination, with the seagrass bed ecosystem, characterized by a canopy cover exceeding 50% and the mangrove forest ecosystem, serving as a crossing route. To ensure comprehensive coverage, phytoplankton sampling was repeated three times at each location to capture the diversity of phytoplankton species within each ecosystem.

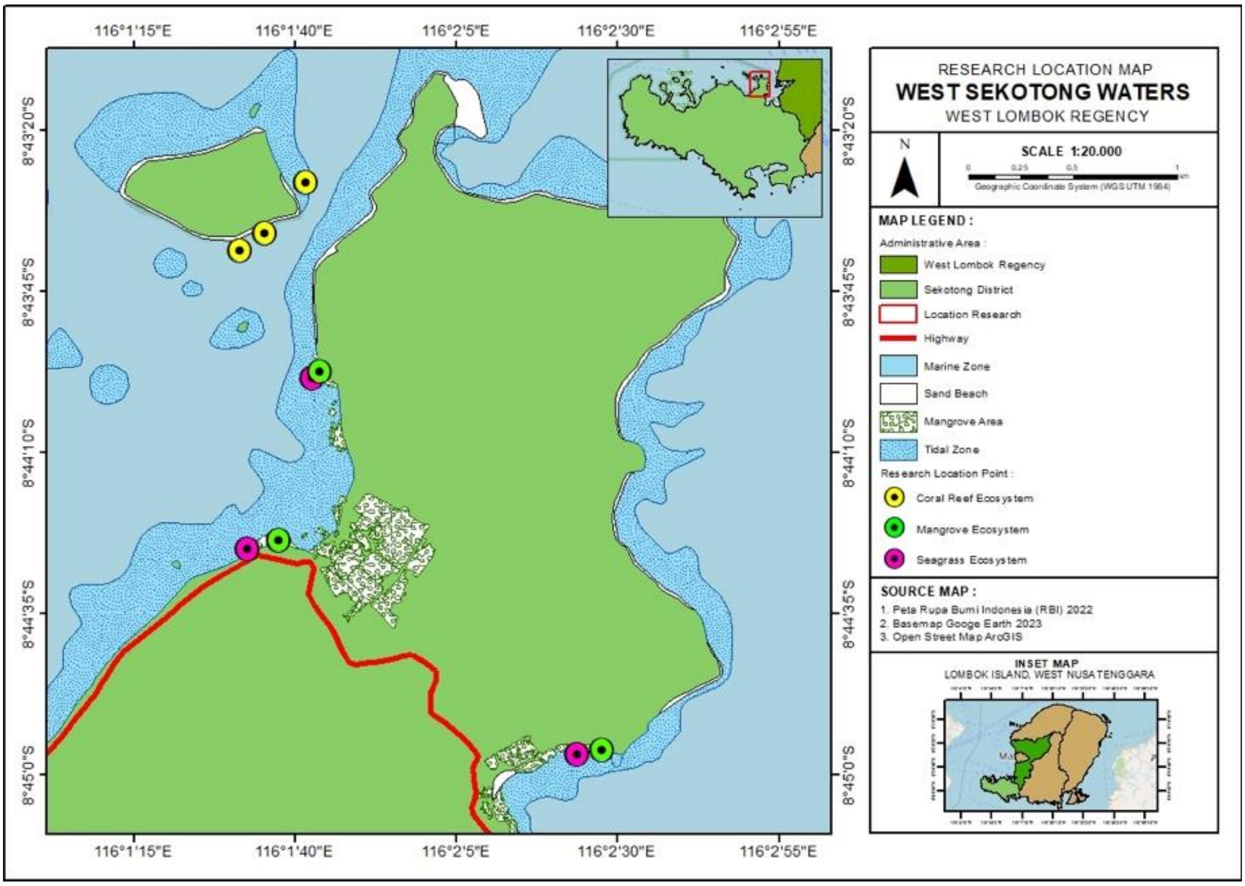

Figure 1. Research site

Material

The equipment utilized in this research encompassed a 5L plastic bucket, plankton net with 25 µm mesh size, 27 plastic bottles (each with a 50 mL capacity), digital pH meter, nitrate testing strips, thermometer, hand refractometer, Sachi disk, GPS device, binocular microscope, pipette, slides and covers, cameras, and both Plankton Identification Book by Yamaji (1996) and Harmful Microalgae Identification Book by Lassus et al. (2016) as references. The materials employed including seawater samples, phytoplankton samples, and 37% formalin solution for preservation.

Phytoplankton Sample Collection and Procedure

Phytoplankton sampling was carried out at each ecosystem with three repetitions, meaning that there are 27 samples for all locations. The sampling procedure involved collecting 100 L seawater using a bucket, and then pouring them into the plankton net that had a 50 mL collection bottle position below. Following this step, the filtered seawater, now enriched with phytoplankton specimens, was transferred into sample bottles, each receiving 5 mL of a 37% formalin solution for preservation. These sample bottles were meticulously labeled and taken to the laboratory for detailed observed under a microscope with a magnification of 10 x 10 and

40 x 10. 1 mL of the homogenized samples was dripped on glass and covered with cover glass, then captured with camera, this observation was repeated three times for each bottle sample then identified and the abundance calculated. Identification of phytoplankton species was by using identification books by Yamaji (1996) and Lassus et al. (2016).

Measurement of Water Physicochemical Parameters

Measurements of water physicochemical parameters were carried out at the same locations as phytoplankton collection. The analytical technique for assessing water samples refers to Effendi (2003), the measurement of environmental parameters was conducted in situ at multiple station points. Subsequently, the average for each water sample was calculated. Measurement of environmental parameters encompassed temperature, salinity, water clarity or turbidity, currents strength, nitrate levels, and pH of the water.

Data Analysis

The abundance of phytoplankton was calculated referring to APHA (1989).

$$N = \frac{Oi}{Op} \times \frac{Vr}{Vo} \times \frac{1}{Vs} \times \frac{n}{p} \qquad (1)$$

N = Phytoplankton abundance (cells/L)
Oi = Cover glass area (484 mm^2)
Op = One wide field of view under microscope (1,306 mm^2)
Vr = Volume of filtered sample (50 ml)
Vo = Concentrate volume of glass (0.05 ml)
Vs = Volume of filtered water sample (100L)
n = Number of phytoplankton on one wide field of view (cells)
p = Number of wide fields of view under microscope (6)

Dominance index was determined using the following formula.

$$C = \sum_{i=1}^{n} \left(\frac{ni}{N}\right)^2 \qquad (2)$$

C = Simpson dominance index
ni = Number of individual species-ith
N = Total number of individuals
n = Number of genera

Similarity index was determined using the following formula.

$$S = \frac{2C}{A + B} \times 100\% \qquad (3)$$

S = Similarity index
A = Number of species in an ecosystem
B = Number of species in B ecosystem
C = Total number of species in ecosystem A and B

Richness index was determined using the following formula.

$$R = \frac{(S - 1)}{\ln (N)} \qquad (4)$$

R = Margalef richness index
S = Number of species
N = Total number of individuals

Result and Discussion

The Presence of Phytoplankton Species in Various Ecosystems in West Sekotong Coastal

The research revealed the presence of 9 classes of phytoplankton with varying distribution across the mangrove forest, seagrass bed, and coral reef ecosystems in West Sekotong coastal areas (Table 1).

Table 1. Distribution of phytoplankton on mangrove forest ecosystem, seagrass bed and coral reef ecosystem

Classes	Family	Species	Ecosystems
Bacillariophyceae	Naviculaceae	*Gyrosigma strigilis*	M, S
		Gyrosigma tenuissimum	M, S
		Gyrosigma attenuatum	S
		Gyrosigma balticum	S
		Gyrosigma fasciola	S
		Navicula grevillei	M, C
		Navicula transitans	M
		Navicula arenaria	S
		Navicula oblonga	S
		Navicula cryptocephala	C
		Navicula impercepta	C
		Navicula radiosa	C

	Meuniera membranacea	C
Diploneidaceae	*Diploneis crabo*	C
	Diploneis novaeseelandiae	C
Amphipleuraceae	*Frustulia rhomboides*	C
	Frustulia vulgaris	C
Pleurosigmataceae	*Pleurosigma elongatum*	S
Amphipleuraceae	*Amphiprora alata*	S
Achnanthaceae	*Achnanthes dispor*	S
	Achnanthes kuwaitensis	S, C
Mastogloiceae	*Mastogloia fimbriata*	M
	Mastogloia braunii	S
	Mastogloia exilis	S
	Mastogloia lanceolata	S
	Mastogloia depressa	C
Bacillariaceae	*Nitzschia filiformis*	M, S
	Nitzschia longissimi	M, S, C
	Nitzschia spatulatha	M, C
	Nitzschia marilenta	C
	Nitzschia frigida	S
	Nitzschia improvisa	S
	Nitzschia jelineckii	S
	Nitzschia longissima	S
	Nitzschia lorenziana	S
	Nitzschia sigma	S, C
	Nitzschia sigmoidea	S, C
	Nitzschia voldcostata	S
	Nitzcshia acicularis	S
	Bacillaria paxillifera	S
	Bacillaria paradoxa	C
	Cylindrotecha Closterium	S
Chaetocerotaceae	*Chaetoceros affinis*	M, S
	Chaetoceros curvisetus	M, S
	Chaetoceros decipiens	M
	Chaetoceros peruvianus	M
Surirellaceae	*Surirella frustosa*	M
	Surirella tenera	M
	Campylodiscus biangulatus	C
Entomoneideaceae	*Entomoneis paludosa*	M
	Entomoneis alata	C
Fragilariaceae	*Synedra ulna*	M, S, C
	Synedra accus	S, C
	Synedra bilunaris	C
Thalassionemataceae	*Thalassionema nitzschioides*	M, S
	Thalassiothrix longissimi	S
Thalassiophysales	*Amphora laevis*	C
	Amphora ovalis	C
Asterionellopsidaceae	*Asterionellopsis glacialis*	M

	Tabellariaceae	*Asterionella Formosa*	S
		Asteroplanus karianus	S
	Grammatophoraceae	*Grammatophora marina*	S, C
		Grammatophora oceanica	S, C
	Licmophoraceae	*Licmophora flabellate*	S, C
		Licmophora grandis	S, C
		Licmophora remulus	S,
	Cocconeidaceae	*Cocconeis stauroneiformis*	S, C
		Cocconeis bradawillensis	C
		Cocconeis pseudomarginata	C
	Eunotiaceae	*Eunotia gracile*	S
	Gomphonemateceae	*Gomphonema affine*	C
		Gomphonema gracile	C
	Pinnulariaceae	*Pinnularia butantanum*	M
Coscinodiscophyceae	Rhizosoleniaceae	*Rhizosolenia bergonii*	M, C
		Rhizosolenia clevei	M, S, C
		Rhizosolenia crassa	M, S
		Rhizosolenia hebetate	M, C
		Rhizosolenia imbricate	M, S, C
	Coscinodiscaceae	*Coscinudiscus radiatus*	M, C
		Coscinodiscus asteromphalus	S
	Triceratiaceae	*Triceratium reticulum*	M, S, C
		Triceratium alternans	C
	Melosiraceae	*Melosira varians*	M, S, C
		Melosira sulcate	C
Cyanophyceae	Oscillatoriaceae	*Oscillatoria limosa*	M, S, C
		Oscillatoria corraline	S
		Oscillatoria tennuis	M
	Nostocaceae	*Anabaena* sp.	M
Chlorophyceae	Selenastraceae	*Ankistrodesmus spiralis*	M, S
		Ankistrodesmus densus	C
		Ankistrodesmus falcatus	C
	Treubariaceae	*Treubaria triappendiculata*	M
Dinophyceae	Ceratiaceae	*Ceratium brave*	S
		Ceratium lineatum	S
		Ceratim furca	C
		Ceratium fusus	C
		Ceratium hexacanthum	C
		Ceratium macroceros	C
		Ceratium micans	C
		Ceratium tripos	C
	Gonyaulacaceae	*Gonyaulax spinifera*	C
	Protoperidiniaceae	*Protoperidinium oceanicum*	C
Zygnematophyceae	Zygnematophyceae	*Spirogyra corrugate*	M
		Spirogyra denticulate	M
		Spirogyra hopiensis	S
Euglenophyceae	Euglenaceae	*Euglena oblonga*	M

Noctilucophyceae	Noctolucaceae	*Noctiluca scintillans*	S
Mediophyceae	Skeletonemataceae	*Skeletonema costatum*	M, S, C
	Stephanodisceae	*Cyclotella meneghiniana*	M, S, C

Description: M = Mangrove Forest, S = Seagrass bed, C = Coral reef

The classification of phytoplankton by class shows that Bacillariophyceae is the most frequently encountered class across all three ecosystems. This is the characteristic of major marine coastal ecosystems, because Bacillariophyceae have high adaptation to their environment (Oseji et al., 2018; Pratiwi et al., 2023). The euryhaline character makes Bacillariophyceae able to live in the salinity range of 5-30 ppt (Kamakura et al., 2022). Moreover, increased nutrient levels in the water prompt Bacillariophyceae to undergo mitotic division at a rate three times higher within a 24-hour period compared to other classes exposed to the same conditions and nutrient levels (Sulistyowati et al., 2016).

Phytoplankton samples were collected from both mangrove forests and seagrass bed ecosystems which are in proximity to residential areas. The disposal of household waste, including food scraps by the local community, in addition to the recreational snorkeling activities in coral reef ecosystems, contributes to an increase in nitrate nutrient levels. Consequently, these elevated nitrate levels have a direct impact on the abundance of Bacillariophyceae. Another factor influencing the prevalence of Bacillariophyceae in this study is the time of sampling, which typically occurred between 08:00 and 12:00 WITA (Central Indonesian Time). This timeframe corresponds to the optimal period for phytoplankton photosynthesis. Bacillariophyceae exhibit positive phototaxis, leading to an increase in their cell numbers during daylight hours when light penetration is at its peak (Serodio et al., 2023).

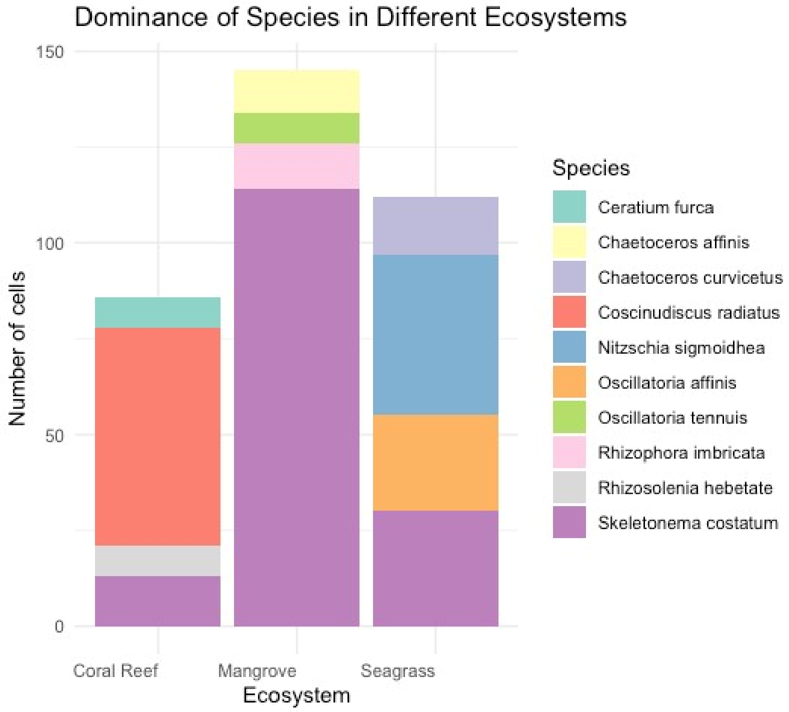

Figure 2. Dominance of Species in Different Ecosystems

In the mangrove forest ecosystem of West Sekotong, various classes of phytoplankton were identified, including Bacillariophyceae, Zygnematophyceae, Euglenophyceae, Cyanophycea, Coscinodiscophyceae, Mediophyceae and Chlorophyceae. The diversity of phytoplankton species in this ecosystem can be attributed to the fertile nature of mangrove forests, which contribute a substantial amount of organic material to the surrounding waters. As the detritus from fallen mangrove leaves enters the water, it undergoes decomposition by microorganisms, ultimately transforming into inorganic materials. Phytoplankton utilize these inorganic materials for assimilation. The presence of detritus from mangrove leaves plays a vital role as an energy source for various marine organisms, including phytoplankton (Tang et al., 2016). Notably, the

Tanjung Kelor and Batu Kumbu areas feature open and exposed mangrove forest ecosystems, allowing sufficient sunlight to penetrate the waters and enabling phytoplankton to carry out optimal photosynthesis. Conversely, in the Medang area, mangrove growth is less dense compared to the other two locations, leading to the presence of phytoplankton. Some mangrove genera found in the research area, such as Rhizophora, Avicenia, and Soneratia, possess roots that mitigate wave action, creating relatively calm waters with a minimal current of approximately 0.06 m/s. This characteristic benefits phytoplankton, as their passive nature makes them less susceptible to displacement by currents and facilitating their reproduction.

In the seagrass ecosystem of West Sekotong coastal, phytoplankton are categorized into 8 classes, including Bacillariophyceae, Dinophyceae, Chlorophyceae, Mediophyceae, Coscinodiscophyceae, Cyanophyceae, Zygnematophyceae and Noctilucophyceae. Noctilucophyceae were exclusively detected within seagrass ecosystems. *Noctiluca scintilans*, characterized by its colorless chlorophyll composition, appears transparent when observed under a microscope. This species is typically found in tropical coastal regions, thriving in habitats with low salinity. Consequently, its abundance is primarily limited to coastal areas, as evidenced in this study where it was exclusively identified in seagrass ecosystems. Furthermore, Noctilucophyceae tends to proliferate during the dry season, and the sampling for this study was conducted in May to coincide with the presence of *Noctiluca scintillans*. In seagrass ecosystems, phytoplankton thrive by floating within the water column and as epiphytes attached to seagrass leaves. The abundance of phytoplankton in seagrass ecosystems benefits from the shallow nature of the seawater, allowing sunlight to penetrate effectively. This study recorded an average water clarity of 0.5 m in the seagrass ecosystem, indicating relatively low turbidity. Consequently, optimal sunlight penetration facilitates the process of photosynthesis for phytoplankton in this environment.

Another influential factor affecting the presence of phytoplankton in this seagrass bed ecosystem is the weak current, measuring approximately 0.03 m/s. These mild currents impose limitation on the dispersion of phytoplankton to other locations. Additionally, the relatively elevated nutrient content, particularly nitrate levels of approximately 0.001 mg/L within the seagrass ecosystem, is presumed to result from nitrogen binding from the atmosphere and the decomposition of deceased seagrass plants into organic matter, thereby fostering phytoplankton growth. Furthermore, the proximity of the seagrass ecosystem to the coastline in West Sekotong enhances the nutrient concentration in the waters due to runoff from the adjacent land.

Similar to the mangrove forest ecosystem, the coral reef ecosystem has also revealed the presence of 6 phytoplankton classes, including Bacillariophyceae, Dinophyceae, Cyanophyceae, Coscinodiscophyceae, Mediophyceae, and Conjugatophyceae. The coral reef ecosystem in West Sekotong is in proximity to hotel and recreational areas, commonly frequented by tourists for snorkeling activities. The presence of anthropogenic activities and snorkeling excursions is believed to contribute to an increase in nutrient levels and water agitation, leading to a relatively abundant presence of phytoplankton. This assertion was substantiated during the sampling process, with numerous remnants of leaves and other household waste observed floating on the water's surface. Furthermore, the tranquil water current (approximately 0.04 m/s) in the research location prevents phytoplankton dispersion to other areas, while a luminosity of 3.5 m optimizes the photosynthesis process.

In contrast the other two ecosystems, the coral reef ecosystem does not contain phytoplankton from Chlorophyceae class. This absence can be attributed to the presence of Chlorophyceae for environment with lower salinity levels, unlike the marine waters in the coral reef ecosystem, which have higher salinity levels (Bellinger & Sigee, 2010). In this study, the salinity in the coral reef ecosystem measured 33.6 ppt, the highest among the three ecosystems. It is suspected that this high salinity is the reason why Chlorophyceae were not found in the coral reef ecosystem of West Sekotong coastal.

Table 2. Water parameter in mangrove forest ecosystem, seagrass bed and coral reefs ecosystem

Environmental Parameters	Mangrove Forest	Seagrass bed	Coral Reefs
Water temperature (°C)	29	29	28.7
Salinity (ppt)	32.7	33	33.6
Current length (m/s)	0.06	0.03	0.04
Turbidity (m)	0.65	0.5	3.5
pH	7.3	7.5	7.7
Nitrate (mg/L)	0.01	0.01	0.01

Distribution and Abundance of Phytoplankton in West Sekotong Coastal

The distribution and abundance of phytoplankton can be influenced by the environmental characteristics of their habitat. Each ecosystem is dominated by specific types of phytoplankton, each possessing unique cells characteristics. In the mangrove forest ecosystems, a total of 37 species and 264 phytoplankton cells was identified, with *Skeletonema costatum* being the dominant species, comprising 114 cells. While *S. costatum* was also found in the other research ecosystems, it did not dominate as in the mangrove forest. The prevalence of *S. costatum* in the mangrove forest ecosystem can be attributed to its adaptability to various aquatic conditions. According to Redzuan & Milow (2019), the abundance of *S. costatum* in the mangrove forest ecosystem is influenced by environmental factors such as temperature and nutrient availability, particularly nitrate. The high nitrate content stimulates the growth of *S. costatum* cells, leading to the formation of chains containing up to 10 cells. Further details from Kaeriyama et al. (2011) suggest that the *Skeletonema* genus can thrive in temperatures ranging from 10 to 34°C. This research confirmed a temperature of 29°C in the mangrove forest ecosystem, along with a nitrate content of 0.001 mg/L. This nitrate concentration falls within the seawater quality standards outlined in KEPMENLH No 51 2004 (Kementerian Negara Lingkungan Hidup, 2004), indicating that marine biota including phytoplankton can thrive in waters with nitrate levels around 0.0008 mg/L. It is likely that this relatively high nutrient content is a result of land runoff, as all three sampling stations are situated in proximity to residential areas.

S. costatum stands out as a unique phytoplankton due to its widespread presence across various aquatic environments and its adaptability to a wide range of temperatures and salinity levels. This adaptability makes it commonly found in tropical climates including the waters of West Sekotong. Suantika et al. (2017) proposed that the growth of *Skeletonema* is triggered by organic nutrients that serve as spore formers, such as Vitamin B12, present in its cells. *S. costatum* has been observed to thrive in different salinity ranges. In our study, the salinity levels across the three ecosystems ranged from 32 to 33 ppt. Research by Supriyantini (2013) indicates that at 15 ppt salinity, protein levels in *S. costatum* cells increase at 25 ppt fat levels in cells increase, and at 30 ppt salinity, Extracted Material Without N Elements levels in the cells increase. This wide range of salinity tolerance allows *S. costatum* cells to produce cell biomass and maintain a balanced composition in varying salinity conditions.

Another prominent phytoplankton species in the mangrove forest ecosystem is *Chaetoceros affinis*, comprising a total of 11 cells. Sahabuddin et al. (2020) note that the growth and abundance of Chaetoceros are significantly influenced by sunlight, allowing it to carry out photosynthesis optimally during daylight hours. Additionally, there are several genera exclusive to mangrove forest ecosystems and not found in other environments. These include the Anabaena genus from the Cyanophyceae class, Treubaria from the Chlorophyceae class, and Pinnularia and Surirella from the Bacillariophyceae class. Some of these genera are typically associated with waters featuring moderate salinity levels. Our research has confirmed a salinity of 32.7 ppt in the mangrove forest ecosystem of West Sekotong waters. Anabaena, for instance, is commonly found in waters with a pH range of 6.8-7, such as shallow lakes or eutrophic waters. The mangrove forest ecosystem in West Sekotong waters maintains a pH of 7.3. Furthermore, the presence of air bubbles often leads to Anabaena being found near the water's surface (Sulastri, 2018).

In the seagrass ecosystem of West Sekotong coastal, phytoplankton identification revealed 58 species and 258 cells, predominantly featuring the *Nitzschia sigmoidhea* species, totaling 42 cells. The cell morphology of *N. sigmoidhea* is characterized by a flat and elongated shape, forming a sigmoid resembling the letter 'S,' with both ends of the cell rounded. *N. sigmoidhea* is frequently found in abundance on the water's surface, particularly at the tips of seagrass leaves. This surface positioning allows for optimal photosynthesis of both phytoplankton and seagrass leaves, facilitated by easy penetration of sunlight. The abundance of *N. sigmoidhea* in the seagrass ecosystem can be attributed to its motile nature in various types of aquatic substrates, aided by its adhesive properties in the form of gelatinous extrusions that adhere to seagrass leaves and other substrates. The seagrass beds in West Sekotong waters are characterized by a muddy sand substrate. Furthermore, *N. sigmoidhea* exhibits a high tolerance for aquatic environments, enabling its survival even in polluted conditions (Permatasari et al., 2016).

NItzschia demonstrates remarkable adaptability, thriving within a wide salinity range of 6–48 ppt, and it can endure temperatures ranging from 5 to 30°C, with an optimal growth rate (Puspitasari, 2017). Our temperature measurements within the seagrass ecosystem registered 29°C, with a salinity level of 33 ppt. These environmental conditions provide robust support for the proliferation of *N. sigmoidhea* in the seagrass ecosystem of West Sekotong waters. Nybakken & Bertness (2005) elaborated on the enhanced nutrient absorption capabilities of *N. sigmoidhea*, highlighting its rapid response compared to other phytoplankton types.

In addition to Nitzschia, phytoplankton in the seagrass ecosystem also originate from the genera Chaetoceros and Skeletonema. Chaetoceros, characterized by chaeta and a chain-like cell morphology, exhibits remarkable resilience in high-current environments (Lee & Lee, 2011). Furthermore, several phytoplankton genera are exclusive to seagrass ecosystems and are not found in other habitats. These genera include Amphiprora, Pleurosigma, Noctiluca, Thalassiothrix, and Cylindrotecha. Research by Hulopi

(2016) revealed that Pleurosigma and Thalasiothirix are frequently encountered in epiphytic communities, ranging from the base to the tips of *E. acroides* seagrass leaves. A similar pattern was also documented by Silalahi et al. (2015), where Amphiprora often serves as an epiphyte on *E. acroides* seagrass leaves, its adhesive properties preventing it from being easily carried away by currents.

The observation of phytoplankton samples in the coral reef ecosystem yielded a total of 46 species and 220 cells, predominantly featuring *Coscinodiscus radiatus*, comprising 57 cells. Microscopic analysis at 40x magnification revealed *C. radiatus* cells displaying brown, yellow, and some green hues, with a round disk-shaped cell morphology. Purnamaningtyas (2019) elucidated Coscinodiscus in high abundance almost year-round in marine waters, spanning estuarine and coastal habitats. The prolific growth of Coscinodiscus is attributed to its rapid nutrient absorption capabilities, outpacing other diatom species thus facilitating optimal physiological processes like respiration and photosynthesis (Mery et al., 2018).

Several phytoplankton genera like Gonyaulax, Diploneis, Frustulia, Amphora, Campylodiscus, Ghomponema, and Protoperidinium, exclusively inhabit coral reef ecosystems. Gonyaulax, distinguished by its two flagella extending along the cell's path, plays a vital role in providing support and balance to prevent easy displacement by currents and their dispersion to other locations. Mujib et al. (2015) reported a positive correlation between the presence of Gonyaulax and water clarity. In this study, the coral reef ecosystem exhibited exceptional brightness, reaching depths of up to 3.5 meters, a stark contrast to the other two ecosystems. Even when observing the water's bottom, clarity remained exceptional. This high level of brightness offers Gonyaulax a unique habitat exclusive to coral reef ecosystems.

Among the phytoplankton species found in all three ecosystems are *Rhizosolenia imbricata, R. clevei, Skeletonema costatum, Cyclotella meneghiniana, Triceratium reticulum, Melosira variance, Oscillatoria limosa, Synedra ulna, and Nitzschia longissima*. Rhizosolenia, characterized by its cylindrical cell morphology with valves at both ends, exhibits sensitivity to current strength (Widianingsih et al., 2007). In the waters of West Sekotong, where current conditions are relatively modest (0.06 m/s in the mangrove forest ecosystem, 0.03 m/s in the seagrass ecosystem, and 0.04 m/s in the coral reef ecosystem), the presence of Rhizosolenia remains consistent across all ecosystems. Additionally, salinity levels in the three ecosystems, ranging from 32-33 ppt, further support the presence of Rhizosolenia. This aligns with research by Widianingsih et al. (2007), which found Rhizosolenia to thrive consistently in environments with salinity levels of 32.64-32.95 ppt.

The observation of *C. meneghiniana* under a microscope, magnified at 40x10, reveals round cell morphology, often yellow but sometimes green and found in colonies. *C. meneghiniana* lacks locomotion and, thus, its distribution is influenced by water currents (Mawarni et al., 2020). This species exhibits a wide distribution, due to its ability to adapt to various environmental conditions. This adaptation is achieved by reducing the rate of photosynthesis during the day through the production of photooxidative destruction enzymes (Wetzel, 1975). The distribution of *C. meneghiniana* is also affected by the depth of each research ecosystem, being found at 0.65 m in the mangrove forest ecosystem, 0.5 m in the seagrass ecosystem, and up to 3.5 m in the shallow coral reef ecosystem, where nitrate content is relatively high at 0.001 mg/L throughout the ecosystem. *C. meneghiniana* is commonly located in shallow water habitats with abundant nutrients (Lowe & Kheiri, 2015). Similar to *C. meneghiana*. *S. ulna* is widely distributed along the West Sekotong coast, influenced by nutrient richness, particularly nitrate. Its high environmental tolerance is attributed to cells having a layered sheath, which enables the accumulation and storage of nutrients as insoluble polymers (Samudra et al., 2003). The West Sekotong coastal region sample sunlight penetration, supporting the metabolic activity of *S. ulna*.

O. limosa exhibits a cylindrical cell morphology with interior cell divisions. Kamilah et al. (2014) explained that *O. limosa*'s layered cell envelope allows it to thrive in various environments, even under stress, making it a common presence in various ecosystems along the West Sekotong coast. Meanwhile, the prevalence of *M. variant* in all ecosystems can be attributed to its adaptability to both open and closed water habitats, such as mangrove forest ecosystems. These two forms can float on the water's surface in coral reef ecosystems or associate with mangrove roots or seagrass plants.

Table 3. Ecological index of phytoplankton in mangrove forest, seagrass bed and coral reefs ecosystem

Ecological index	Mangrove Forest	Seagrass bed	Coral Reefs
Number of cells	264	258	220
Richness index (R)	6.45	10.26	9.83
Dominance index (C)	0.19	0.06	0.08

Ecological index analysis was conducted to assess the condition of phytoplankton resources throughout the research. The results indicate differences among the three ecosystems along the West Sekotong coast. Both the seagrass and coral reef ecosystems exhibit high phytoplankton diversity, with no dominant type, reflected in the low dominance index (C) values (0.06 for seagrass and 0.08 for coral reef ecosystems). The low dominance index values are accompanied by high species richness index (R) values, indicating high species diversity (R > 5) in each ecosystem (mangrove forest: 6.45, seagrass: 10.26, and coral reef: 9.83).

The percentage of similarity index value between mangrove forest and seagrass ecosystems is 35.89%, indicating a moderate degree of habitat similarity. This similarity is reflected in shared temperature values of 29°C and similar brightness levels ranging from 0.5 to 0.65 m. In contrast, the percentage of phytoplankton similarity index between mangrove forest and coral reef ecosystems is the lowest among the comparisons, at 30.87%. The differences in habitat characteristics, such as salinity (32.6 ppt in mangrove forest and 33.7 ppt in coral reef ecosystems), contribute to this lower similarity index. These values suggest that phytoplankton distribution in each ecosystem in West Sekotong waters occurs evenly and relatively stable, promoting ecosystem balance. These balanced conditions are supported by productive habitats with high nutrient content and minimal pollution.

Although the environmental conditions in West Sekotong coastal are within acceptable limits according to water quality standards for phytoplankton habitats, several phytoplankton species found in all three ecosystems have the potential for harmful algae blooms. These species include *Skeletonema costatum, Noctiluca scintillans, Protoperidinium oceanicum, Gonyaulax spinifera, Anabaena* sp, and *Chaetoceros peruvian*. Lassus et al. (2016) explained that *Noctiluca scintillans* can serve as a vector or carrier of DSP and ASP toxins. *Noctiluca scintillans, Skeletonema costatum, Ceratium furca, Anabaena* sp., and *Prorocentrum minimum* can cause red tide phenomena but are not toxic to marine life. The occurrence of these blooming and harmful algae can be attributed to eutrophication, which is the enrichment of nutrients. It is possible that phytoplankton with the potential to be harmful algae bloom will continue to exist and thrive in the ecosystems of the West Sekotong coastal and potentially negatively affecting marine life, humans, and the ecosystems themselves. Moreover, these three ecosystems in this region are of strategic importance. Therefore, it is essential to establish rules or policies regarding the protection of the mangrove, seagrass, and coral reef ecosystems in the West Sekotong area. This should include raising awareness among local communities and tourists not to indiscriminately dispose of waste in coastal areas and conducting regular monitoring of the presence and distribution of phytoplankton in each ecosystem.

Conclusion

The mangrove ecosystem is primarily dominated by *Skeletonema costatum*, the seagrass bed by *Nitzschia sigmoidhea*, and the coral reef ecosystem by *Coscinodiscus radiatus*. Additionally, several phytoplankton species consistently inhabit each of these ecosystems, including *Rhizosolenia imbricata, R. clevei, Skeletonema costatum, Cyclotella meneghiana, Triceratium reticulum, Melosira varian, Oscillatoria limosa, Synedra ulna,* and *Nitzschia longissima*. The distribution of these phytoplankton species in the West Sekotong coast is relatively uniform and stable. Among these ecosystems, the highest degree of similarity is observed between the mangrove forest and seagrass beds (35.89%). Conversely, the lowest similarity index is found between the mangrove forest and coral reef ecosystem (30.87%). The species richness index (R) values, ranging from 6.45 to 10.26 in all three ecosystems, reflect a high level of species diversity. Consequently, the dominance index (C) values in each ecosystem are low. Furthermore, the environmental parameters measured in the ecosystems along the West Sekotong coast exhibit no significant differences and conform to the quality standards for marine biota established by KEPMENLH No 51 2004 (Kementerian Negara Lingkungan Hidup, 2004). Therefore, it can be confidently concluded that the West Sekotong coastal area remains a suitable and productive habitat for phytoplankton.

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Author Contributions

All authors have contributed to the final manuscript. The contribution of each author as follow, collected and analyze the data, drafted the manuscript, and designed the figures and table, A.U.M. and D.A.C.; devised the main conceptual ideas and critical revision of the article, S.P.A., H.A., and S. All authors discussed the results and to the published version of the manuscript.

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Conflicts of Interest

The author declares that they have no competing interest.

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