JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(8), 1–11
https://doi.org/10.12911/22998993/162776
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.03.11
Accepted: 2023.06.16
Published: 2023.06.20

Assessing Environmental Factors on the Growth and Distribution of Mangrove Seedlings Along the Bintuni Riverbank Area, Bintuni Bay, West Papua, Indonesia

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ABSTRACT

Bintuni Bay is considered one of the largest mangrove ecosystems in the world, and it has benefited a lot to local inhabitants and the surrounding ecosystem by underpinning and maintaining ecosystem balances. This study assesses various environmental factors that affect the flow of the Bintuni River and mangrove ecosystems as a result of potential degradation due to various anthropogenic activities and small-scale industries along the river. Several environmental parameters were collected, measured, and analyzed in the laboratory, while mangrove seedlings were measured and calculated at five different locations to obtain the importance value index (IVI). The results indicated slightly varied environmental parameters and concentrations at the five locations. However, there was no significant difference in the environmental parameters between the five different locations (p-value of $0.953 > 0.05$, 95% of CI). Mangrove seedlings were distributed evenly along the five different locations which were indicated by the number of individuals (ind/ha). There was no significant correlation among these environmental parameters because of the low concentrations of chemical and biological compounds in the water. Moreover, mangroves can regenerate, grow, and exist even in extreme and unbalanced environmental niches.

Keywords: mangrove seedlings, environmental factors, anthropogenic activities, water pollution, mangrove density, Bintuni river.

INTRODUCTION

Mangrove forests are intertidal forest ecosystems that are dominantly distributed in tropical and sub-tropical regions across the globe (Teutli-Hernández et al., 2020). Mangrove ecosystems play pivotal ecological roles as habitats for various flora and fauna (Srikanth et al., 2015; Carugati et al., 2018). From a socioeconomic perspective, mangroves provide various sources of livelihood to communities living around them, including fisheries, building materials, firewood, charcoal products, foods, and medicines, and handicraft products (Vo et al., 2012; Aye et al., 2019; Nyangoko et al., 2021). Mangrove forests with high biological diversity are more likely to be highly productive, not only in terms of providing a variety of forest products but also in maintaining estuarine water quality, an important aspect of the environment for fauna that is often consumed by humans (Orchard et al., 2016; Mcllveen and Hung, 2019; Shaikh et al., 2021). Mangroves are also considered important for preventing abrasion and natural disasters, such as tsunamis and storms, and are capable of absorbing large sea waves. Mangrove forests can also protect wetland crops and other coastal vegetation from damage due to storms and salination through filtration.

Mangrove growth is inevitably correlated with surrounding environmental factors and is greatly affected by changes in hydrooceanographic dynamics, which lead to coastal damage (Tran and Fischer, 2017; Kibler et al., 2022; Ahmed, 2022a). One factor affecting the most damaged mangrove forests is anthropogenic activities in the mangrove area, as many daily human activities impact water flow, such as soil substrata contamination, oil spills, and dumping of chemical liquids, detergents, and garbage which eventually polluted the riverbank and mangrove habitat (Nguyen, 2014; Chowdhury et al., 2017; Sruthi et al., 2017; Konom et al., 2019; Edy et al., 2021). Liao et al. (2019) noticed that anthropogenic activities exert high pressure on mangrove forests, which impacts the state of mangrove forest habitats and potentially increases fragmentation, degradation, and habitat loss. The spatial distribution pattern of mangrove trees is caused by changes in the water level, and salinity is considered the main factor (Saha et al., 2020; Bhowmik et al., 2022; Islam et al., 2022). Ahmed et al. (2022b) highlighted salinity as the most restrictive factor that reduces mangrove forest ecosystems and their associations. In addition, the geomorphological characteristics of mangrove development vary substantially (Sarker et al., 2016).

Seedlings are a key factor in mangrove distribution. Seedling establishment and growth extend mangrove distribution and increase land establishment. Kibler et al. (2022) specified that the success of mangrove seedling developments was spurred by suitable habitat characteristics and site hydrodynamics. *Avicennia* sp., at the frontline of mangrove development, is vulnerable to establishment and growth failure caused by improper habitat conditions. Environmental factors, including temperature, salinity, pH, dissolved oxygen (DO), organic matter, nutrients, and sediment structure, including sand and silt composition, are considered to be factors affecting *Avicennia* sp., seedling growth (Hastuti et al., 2012; Su'aidah et al., 2021). Hu et al. (2022) indicated that some fundamental environmental parameters, such as soil characteristics, pH, salinity, and particle sizes, are among the most significant factors affecting mangrove seedling growth. Mangrove soil is an important cycle for bacterial colonies to generate physicochemical soil, which is pivotal for mangrove seedling growth (Hossain et al., 2012). Guo et al. (2013) observed that temperature, carbon dioxide, salinity, light, nutrients, flooding, and specific biotic influences affected seedling survival and growth during the life stages of mangroves. In addition to the salinity, Islam et al. (2022) expressed a correlation between salinity rate and changes in mangrove growth parameters, such as tree diameter, tree height, and basal area

Even though there are many interrelated factors affecting mangrove growth, particularly in the early growth of seedlings, there is still limited knowledge and information on the impacts that specific variation in environmental factors and availability have on mangrove seedlings growth along riverbanks. Therefore, this study investigates the effect of environmental factors on the distribution, composition, and density of mangrove species along the riverbank of the Bintuni River in one of the most extensive mangrove areas in Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted in the Bintuni District, West Papua Province, Indonesia. Data collection was conducted for two weeks in March 2022 along the Bintuni riverbank, which is covered with mangrove species. The study area is a lowland tropical forest with dominant alluvial soil, particularly along the riverbank, and substrate sediment rich in deep organic soils (Sasmito et al., 2020). There were five locations for data collection, namely the Bintuni River estuary, the sub-river estuary, Kamp.Lama01, Kamp.Lama02, and Kamp. Masuhi. The five locations were selected based on mangrove seedlings distribution, the similarity of ecological attributes (i.e., soil characteristics, relative humidity, temperature, and annual precipitation), inundation by river water flow, and the extent to which the area was affected by anthropogenic activities along the Bintuni riverbank.

Data collection

The environmental factors measured in this study were water temperature (°C), total suspended soil (mg/L), total dissolved soil (mg/L), pH, water salinity (‰), DO (mg/L), biological oxygen demand (BOD, mg/L), chemical oxygen demand (COD, mg/L), phosphate (mg/L), ammonia (mg/L), nitrate (mg/l), detergents (mg/L), and oil and fat (mg/L). To obtain water samples from the five locations along the Bintuni River area, a small sample bottle (500 mL) was used to collect surface water along the riverside areas. All sample bottles were then placed in a box to preserve and maintain their temperature for further analysis in the laboratory using a digital thermometer. To characterize the surrounding environmental conditions, short descriptions were made to differentiate the five locations, and biotic and abiotic visualizations were taken using a digital camera.

A transect line was created to acquire mangrove data for seedlings growth with the azimuth designed to be perpendicular toward the contour, meaning that data were acquired from the river bank to the mainland. The observation plots were established along the transect. A total of 165 sampling plots were established, each with a size of 10×10 m, intended only to measure vegetation at the seedling stage. The plot was determined based on location characteristics and accessibility; therefore, the plots were not always linear or perpendicular to the azimuth. Within each plot, all mangrove species were recorded and measured at the tree stage. A mangrove key identification book (Mangrove Guidebook for Southeast Asia) was used to identify species names, which were then confirmed by botanists (Giesen et al., 2006). Mangrove seedlings data were acquired by counting the number of species that were identified and then grouped based on species (Table 1).

Data analysis

All statistical analyses were performed using R statistical software (R Core Team, 2022). The water salinity at the five different locations was measured using a refractometer. DO in the water was analyzed using a DO meter, and BOD was measured using the Lovibond OxiDirect measuring system through the manometric method (Bak et al., 2000). In addition to knowing the total amount of ammonia and nitrate in water, the Indonesian National Standards (SNI) 19-6964.3-2003 and 19-6963.7-2003 have been implemented. Phosphate concentration was measured using the Standard Method 2005, section 4500-P.C. These analyses were performed at the Chemical Laboratory at the University of Papua. All seedlings were recorded on a *tally sheet* and entered into Microsoft Excel for Windows 10 for further data analysis and visualization. A one-way of ANOVA analysis was used to measure the differences among all environmental variables corresponding to their different locations. To create a violin plot that indicates environmental parameter distributions among five different locations, the '*tidyverse*' and '*ggplot2*' packages were used. Mangrove seedling density and frequency at each location were calculated as the IVI by summing up the relative density (RD), and relative frequency (RF). The densest seedling species at each location were shown to determine the distribution of species among the five locations along the Bintuni riverbank. To observe the correlation between environmental factors and mangrove seedling density and frequency in each location, non-metric multidimensional scaling (NMDS) was performed using the '*vegan*' package based on ranked order to accommodate a variety of different environmental parameters in the five different locations.

RESULTS

Water environmental attributes

All measurements were taken along the Bintuni riverbank when the river was at high tide. There were variations among the five locations in terms of water temperature, total suspended soil, total dissolved soil, pH, water salinity, DO, BOD, COD, and quantities of phosphate, ammonia, nitrate, dissolved detergents, oil, and fats in the Bintuni River. However, the one-way ANOVA test indicated no significant difference among the five locations in terms of environmental factors, with *a p*-value of 0.953 > 0.05 with a 95% confidence interval (Figure 1).

Table 1. Distribution of selected location, plot, number of individuals, and its attributes

No	Location distribution	∑ plot	∑ Ind.	Coordinates
1.	River estuary	20	55	2°12'47"S, 133°33'45"E
2.	Sub-river estuary	10	29	2°11'04"S, 133°34'50"E
3.	Kamp.Lama01	60	141	2°08'04"S, 133°33'03"E
4.	Kamp.Lama02	50	146	2°07'49"S, 133°32'29"E
5.	Kamp.Masuhi	25	75	2°06'43"S, 133°31'19"E
Total		165	446	

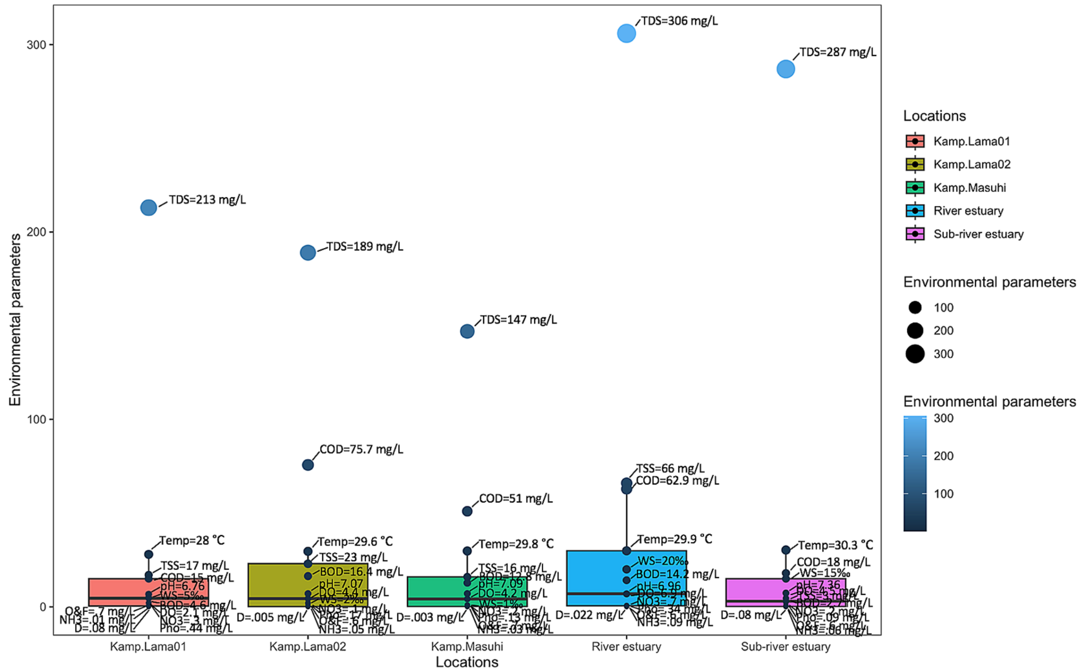

Figure 1. A boxplot showing the distribution of various concentration ranges of environmental factors in the five different study locations along the Bintuni riverbank

Mangrove seedling frequency and distribution

The distribution of mangrove seedlings among the five locations revealed a in frequencies and species. From the five locations, the IVI ecological parameter showed that in Kamp.Lama01 the highest IVI was for *Rhizophora mucronata* (70.32), while the lowest IVIs were for *Bruguiera parviflora* (5.09) and *Dyospiros* sp. (5.09). In the river estuary, the highest IVI was *Rhizophora mucronata* (71.04), while the lowest IVI was *Avicennia officinalis* (3.21). The highest IVI in the sub-estuary belonged to *Rhizophora mucronata* (60.98) as well, while the lowest were *Avicennia officinalis* (5.68) and *Sonneratia alba* (5.68). In Kamp.Lama02, the highest IVI was *Bruguiera parviflora* (51.70), while the lowest IVI was *Aegiceras corniculatum* (2.07). *Avicennia alba* had the highest IVI (56.19) in Kamp.Masuhi, while the lowest IVI was *Xylocarpus moluccensis* (9.62). In terms of mangrove seedling density per hectare among the five different locations, it was found that the highest seedling density was found in Kamp.Masuhi, reaching 3,000 individuals/ha, followed by kamp.lama02 with 2,920 individuals/ha; the third highest seedling density was found in the sub-river estuary area with 2,900 individuals/ha; the fourth highest was found in the river estuary area with approximately 2,750 individuals/ha, and the least density seedlings was found in kamp.lama01 with approximately 2,350 individuals/ha (Figure 2).

DISCUSSION

Variation and distribution of environmental parameters along the Bintuni river

The five study locations were partly indicated to be inundated areas and were considered as intertidal zones in the Bintuni River. The river also functioned as the main alternative route for the sea transportation of local inhabitants to access the municipal city of the Bintuni district. Such a strategic function of the river has a cascading impact on the quality of river water and its flows since multiple anthropogenic activities mainly occurred in the surrounding river area, such as contamination with various chemical compounds, detergents from traditional activities, oil spills from small-scale industries, ship transportation, and any related activities surrounding the municipal area. It I likely that these anthropogenic activities and small-scale industries cause the river to be polluted (de Girolamo et al., 2012; Duwig et al., 2014; Sidabutar et al., 2017).

Water temperature is considered an important abiotic factor because of its fundamental role in

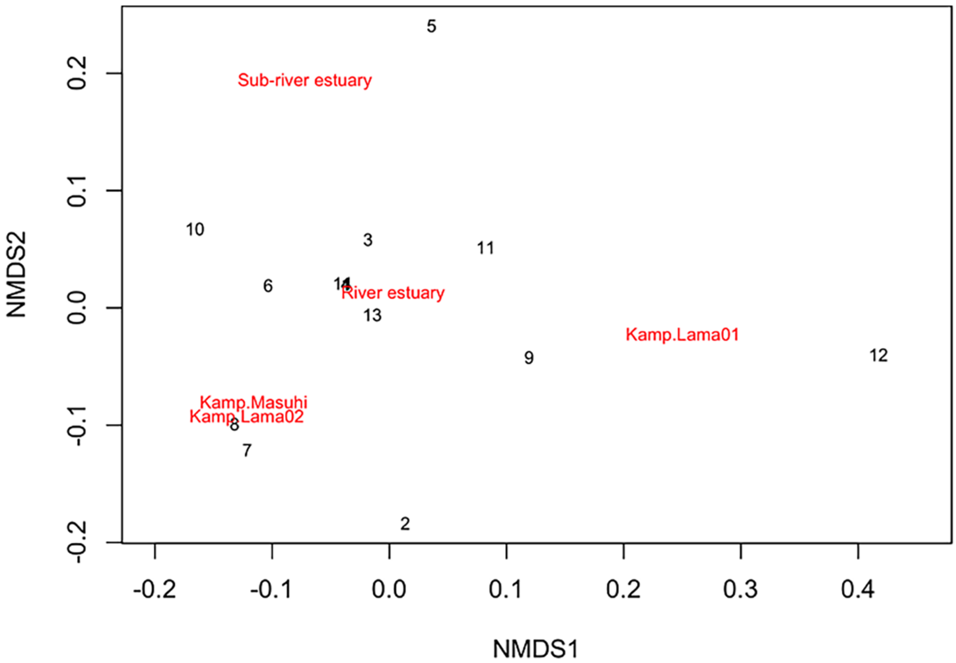

Figure 2. Non-metric multidimensional scaling indicated no significant correlation between various environmental parameters and the mangrove seedling density and frequency (seedlings/ha) recorded from the five different locations along the Bintuni riverbank

aquatic organisms (Li et al., 2022). It has been noted that ocean water temperature varies across the globe by season, depth, latitude, ocean currents, convection, and surrounding environmental conditions (Vreugdenhil and Gayen, 2021). In this study, the water temperatures ranged from 28 °C found in Kamp.Lama01 up to 30.3 °C found in the sub-river estuary area. There was no significant difference among the five locations in terms of the mean water temperature. The range of water temperatures was still considered ideal for supporting the survival of sea microorganisms, such as phytoplankton, as well as the growth of river vegetation, including mangrove seedlings. The range of the mean water temperature found in this study was similar to that measured by Hamuna et al. (2015) around the Jayapura Sea, which is still considered normal based on the Indonesia Sea Water Quality Standards issued by the Ministry of Environment and Forestry no. 51 of 2004. Ximenes et al. (2018) observed the ideal growth and development of propagules of *Avicennia* sp. at a temperature of 25 °C; when the temperature was reduced to 17 °C, there was a strong reduction in the growth and development processes of the propagules. In addition, there was no significant difference in the pH of the water between the five locations, with the pH ranging from 6.76 (the lowest) in Kamp.Lama01 to 7.09 (the highest) in Kamp.Masuhi. The pH range of the water in the Bintuni River was considered normal and ideal for living sea organisms and vegetation to grow (Table 2).

The salinity concentration was slightly scattered across the five different locations, with the highest concentration of water salinity in the river estuary area (20‰) and the lowest in Kamp.Masuhi (1‰). There was clear evidence that in the estuary area, which is close to the sea, the salinity was high compared to the sub-river and the area far from the estuary (Kamp.Masuhi) (Fig. 1). According to Khang et al. (2008), the level of salinity in the five locations ranges from slightly saline (0.5–2.5‰) in Kamp.Masuhi to highly saline (>15‰) in the river estuary. Lower salinity rates in rivers and sub-river areas can be caused by the differentiation of evaporation, precipitation, and run-off from rivers and sub-rivers (Rugebregt and Nurhati, 2020). Nevertheless, mangroves are salt-tolerant plant species that can tolerate highly saline niches and are capable of rejecting potentially harmful salts through the extraction process (Srikanth et al., 2015). Therefore, even though there was variation in salt concentration at the five different locations, it did not affect the growth of propagules and seedlings of mangroves in the study areas (Table 3).

COD represents the amount of oxygen required to oxidize organic materials in the

Table 2. Variation of environmental parameters and statistical attributes among the five different locations along the Bintuni riverbank

Environmental parameters	Kamp. Lama01	River estuary	Sub-river estuary	Kamp. Lama02	Kamp. Masuhi
Temperature (°C)	28	29.9	30.3	29.6	29.8
Total suspended solid/TSS (mg/L)	17	66	3	23	16
Total dissolved solid/TDS (mg/L)	213	306	287	189	147
pH	6.76	6.96	7.36	7.07	7.09
Water salinity/WS (‰)	5	20	15	2	1
DO (mg/L)	2.1	6.9	4.5	4.4	4.2
BOD (mg/L)	4.6	14.2	2.7	16.4	12.8
COD (mg/L)	15	62.9	18	75.7	51
Phosphate/Pho (mg/L)	0.44	0.34	0.09	0.17	0.13
Ammonia/NH_3 (mg/L)	0.01	0.09	0.06	0.05	0.03
Nitrate/NO_3 (mg/L)	0.3	0.7	0.2	0.1	0.2
Detergent/D (mg/L)	0.08	0.022	0.004	0.005	0.003
Oil and fats/O&F (mg/L)	0.7	0.6	0.6	0.6	0.7

Table 3. Distribution of seedling density, frequency, and IVI of the Bintuni riverbank, West Papua, Indonesia

Kamp.lama01						
Species	∑ Ind.	Density	RD	Frequency	RF	IVI
Avicennia alba	16	0.0452	4.5198	0.1333	5.6738	10.1935
Avicennia marina	60	0.1695	16.9492	0.5167	21.9858	38.9350
Bruguiera parviflora	8	0.0226	2.2599	0.0667	2.8369	5.0968
Bruguiera gymnorrhiza	23	0.0650	6.4972	0.2333	9.9291	16.4263
Bruguiera parviflora	32	0.0904	9.0395	0.2000	8.5106	17.5502
Diospyros sp.	8	0.0226	2.2599	0.0667	2.8369	5.0968
Rhizophora apiculata	28	0.0791	7.9096	0.1333	5.6738	13.5834
Rhizophora mucronata	141	0.3983	39.8305	0.7167	30.4965	70.3270
Rhizophora parviflora	20	0.0565	5.6497	0.0667	2.8369	8.4866
Xylocarpus granatum	8	0.0226	2.2599	0.1333	5.6738	7.9336
Xylocarpus moluccensis	10	0.0282	2.8249	0.0833	3.5461	6.3710
Total	354	1.0000	100.00	2.3500	100.00	200.0000
River estuary						
Species	∑ Ind.	Density	RD	Frequency	RF	IVI
Avicennia alba	6	0.0420	4.1958	0.1500	5.4545	9.6503
Avicennia marina	17	0.1189	11.8881	0.4500	16.3636	28.2517
Avicennia officinalis	2	0.0140	1.3986	0.0500	1.8182	3.2168
Bruguiera gymnorrhiza	5	0.0350	3.4965	0.1000	3.6364	7.1329
Bruguiera parviflora	11	0.0769	7.6923	0.3000	10.9091	18.6014
Ceriops tagal	4	0.0280	2.7972	0.0500	1.8182	4.6154
Rhizophora apiculata	10	0.0699	6.9930	0.1500	5.4545	12.4476
Rhizophora mucronata	60	0.4196	41.9580	0.8000	29.0909	71.0490
Rhizophora parviflora	5	0.0350	3.4965	0.0500	1.8182	5.3147
Sonneratia alba	5	0.0350	3.4965	0.1500	5.4545	8.9510
Xylocarpus granatum	8	0.0559	5.5944	0.3000	10.9091	16.5035
Xylocarpus moluccensis	10	0.0699	6.9930	0.2000	7.2727	14.2657
Total	143	1.0000	100	2.7500	100	200.0000

Table 3. Cont.

Sub-river estuary						
Species	∑ Ind.	Density	RD	Frequency	RF	IVI
Avicennia alba	4	0.0471	4.7059	0.2000	6.6667	11.3725
Avicennia marina	13	0.1529	15.2941	0.5000	16.6667	31.9608
Avicennia officinalis	2	0.0235	2.3529	0.1000	3.3333	5.6863
Bruguiera gymnorrhiza	4	0.0471	4.7059	0.3000	10.0000	14.7059
Bruguiera parviflora	3	0.0353	3.5294	0.2000	6.6667	10.1961
Ceriops tagal	4	0.0471	4.7059	0.1000	3.3333	8.0392
Rhizophora apiculata	5	0.0588	5.8824	0.1000	3.3333	9.2157
Rhizophora mucronata	32	0.3765	37.6471	0.7000	23.3333	60.9804
Rhizophora stylosa	7	0.0824	8.2353	0.2000	6.6667	14.9020
Sonneratia alba	2	0.0235	2.3529	0.1000	3.3333	5.6863
Xylocarpus granatum	4	0.0471	4.7059	0.3000	10.0000	14.7059
Xylocarpus moluccensis	5	0.0588	5.8824	0.2000	6.6667	12.5490
Total	85	1.000	100	3.0000	100	200.0000
Kamp.lama02						
Species	∑ Ind.	Density	RD	Frequency	RF	IVI
Aegiceras corniculatum	4	0.0139	1.3937	0.0200	0.6803	2.0740
Avicennia alba	12	0.0418	4.1812	0.1600	5.4422	9.6234
Avicennia marina	23	0.0801	8.0139	0.2800	9.5238	17.5377
Bruguiera gymnorrhiza	48	0.1672	16.7247	0.4800	16.3265	33.0513
Bruguiera parviflora	82	0.2857	28.5714	0.6800	23.1293	51.7007
Diospyros sp.	5	0.0174	1.7422	0.1000	3.4014	5.1435
Heritiera littolaris	30	0.1045	10.4530	0.3000	10.2041	20.6570
Rhizophora apiculata	59	0.2056	20.5575	0.6800	23.1293	43.6867
Rhizophora stylosa	4	0.0139	1.3937	0.0400	1.3605	2.7543
Sonneratia alba	6	0.0209	2.0906	0.0400	1.3605	3.4511
Xylocarpus moluccensis	14	0.0488	4.8780	0.1600	5.4422	10.3202
Total	287	1.0000	100	2.9400	100	200.0000
Kamp.masuhi						
Species	∑ Ind.	Density	RD	Frequency	RF	IVI
Avicennia alba	10	0.0610	6.0976	0.2000	6.5789	12.6765
Avicennia marina	49	0.2988	29.8780	0.8000	26.3158	56.1938
Bruguiera parviflora	14	0.0854	8.5366	0.2400	7.8947	16.4313
Bruguiera sexangula	7	0.0427	4.2683	0.2000	6.5789	10.8472
Rhizophora apiculata	15	0.0915	9.1463	0.2000	6.5789	15.7253
Rhizophora mucronata	49	0.2988	29.8780	0.8000	26.3158	56.1938
Xylocarpus granatum	15	0.0915	9.1463	0.4000	13.1579	22.3042
Xylocarpus moluccensis	5	0.0305	3.0488	0.2000	6.5789	9.6277
Total	164	1.000	100	3.0400	100	200.0000

water, whereas BOD indicates the amount of oxygen consumed by sea organisms and bacteria, which are capable of decomposing organic matter under aerobic conditions (Prambudy and Setiawan, 2019; Qi et al., 2021). This study found the highest COD in Kamp.Lama02 (75.7 mg/L) and the lowest in Kamp.Lama01 (15 mg/L). The highest COD in Kamp.Lama02 was caused by multiple small-scale industrial activities and shipping ports that potentially spill chemical compounds into the river. Moreover, BOD varied across the five locations, where the highest was shown in Kamp. Lama02 (16.4 mg/L) and the lowest was seen in Kamp.Lama01 (4.6 mg/L). The higher BOD represents the high amount of oxygen that exists in the water and benefits the survival of sea microorganisms (Sidabutar et al., 2017). When comparing the dissolved oxygen (DO) parameter, it slightly varied among the five locations, with the highest concentration observed in the river estuary (6.9 mg/L) and the lowest in Kamp.Lama02 (2.1 mg/L) (Table 2). It was apparent that the number of sea microorganisms was higher in the estuary area because of the higher amount of oxygen dissolved in the water (Hamuna et al., 2018) compared to the other four locations that were further from the estuary. According to the Degree of Environment and Forestry Minister of 51 2004 for Sea Water Quality Standards, Kamp.Lama01 (2.1 < 5 mg/L), the sub-river estuary (4.5 < 5 mg/L), Kamp.Lama02 (4.4 < 5 mg/L), and Kamp.Masuhi (4.2 < 5 mg/L) did not fulfill the standard (Hamuna et al., 2018).

Other small amounts of variation from environmental factors such as phosphate, ammonia, nitrate, detergents, oil, and fat were observed in the five locations, which provided no significant difference in terms of impact on the river water. Phosphate was found below 1 mg/L in all study locations, where the highest was indicated in Kamp.Lama01 (0.44 mg/L) and the lowest seen in the sub-river estuary (0.09 mg/L) (Table 2). Ammonia was measured below 1 mg/L in all study locations, where the highest was indicated in Kamp.Lama01 (0.01 mg/L) and the lowest was in the river estuary (0.09 mg/L). Nitrate was also found below 1 mg/L across all study locations, where the highest was measured in Kamp.Lama02 (0.1 mg/L) and the lowest was in the river estuary (0.7 mg/L). Very low concentrations and no significant correlation were observed for detergents, oil, and fat distribution in the five locations, with an overall concentration below 1 mg/L (Table 2). However, according to the Degree of Environment and Forestry Minister of 51 2004 for Sea Water Quality Standards, the phosphate level were higher in Kamp. Lama01 (0.44 > 0.015 mg/L), the river estuary (0.34 > 0.015 mg/L), Kamp.Lama02 (0.17 > 0.015 mg/L), and Kamp.Masuhi (0.13 > 0.015 mg/L). The nitrate concentration was higher at all study locations (> 0.008 mg/L). Conversely, ammonia was found to be lower in all study locations (< 0.3 mg/L) (Hamuna et al., 2018).

Relationship between environmental parameters and mangrove seedling growth

Mangrove seedling density and frequency vary somewhat among the five locations in terms of density per hectare. The highest seedling density per hectare was found in Kamp.Masuhi, with approximately 3,000 individuals/ha, while the lowest was observed in in Kamp.Lama01, with approximately 2,350 individuals/ha. In general, there was a good distribution of seedlings per hectare during the successional phase, and the results of this study were quite similar to those of Hilmi et al. (2017) who measured seedling density per hectare in the successional phase of the mangrove greenbelt area of North Jakarta. This means that all five locations had similar patterns of seedling growth and successional trends in their mangrove ecosystem development. Sraun et al. (2022) noted a high distribution of mangrove tree density per hectare along the Bintuni riverbank, starting from the estuary up to the municipal area far from estuary, even though there was a significant variation in the tree diameter and total height of the mangrove trees along the Bintuni riverbank area. Nihan et al. (2022) indicated that mangrove density is positively correlated with the presence of macrozoobenthos, which are a pivotal component of mangrove forest ecosystems. In general, there was no apparent correlation between the environmental parameters (Table 2) in river water and the presence, growth rate, density, and composition of mangrove seedlings along the Bintuni River. This observation was strengthened by an ANOVA analysis which showed no correlation among the environmental parameters and concentrations at the five study locations (p-value of 0.953 > 0.05, 95% CI). There was no apparent pattern in the distribution of the environmental parameter concentrations along the river, which can be measured as a trend of degradation from mangrove niches and seedling growth, or vice versa (Fig. 1). For example, the increased density of *Sonneratia alba* can be stimulated by a higher concentration of DO in the surrounding water (Villocino et al., 2015). However, there was no indication of this in this study, where the highest DO was found in the river estuary (6.9 mg/L) and the highest IVI from the seedling stage in the area was for *Rhizophora mucronata* (IVI = 71.04). Therefore, this study showed that there was no significant correlation among these environmental parameters because of the low concentration of these chemical and biological compounds in the water. In addition, mangroves can regenerate, grow, and exist in extreme and unbalanced environmental niches (Friess et al., 2012; Srikanth et al., 2015).

CONCLUSIONS

The Bintuni River was considerably affected by various anthropogenic activities by local inhabitants along the river, and it undeniably experienced changes in several environmental parameters owing to contamination with chemical and biological compounds. However, ANOVA analysis indicated no significant difference in the quantities of the environmental parameters and concentrations in the river water across the five sample locations (*p*-value of 0.953 > 0.05, 95% CI). Many mangrove seedlings were distributed across the five locations, with the highest seedling density found in Kamp.Masuhi (3,000 individuals/ha), while the lowest was noted in Kamp.Lama01 (2,350 individuals/ha). This study showed that there was no significant correlation among these environmental parameters due to the low concentration of these chemical and biological compounds in the water and demonstrated the ability of mangroves to exist and tolerate extreme and unbalanced environmental niches across the five different study locations.

Acknowledgements

Acknowledgments are conveyed to the Graduate School of Environmental Science, the University of Papua, Manokwari, Indonesia, for their support of this field research study. We thank the Government of Teluk Bintuni District, West Papua, Indonesia, and all those who assisted with this research.

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