INNSPUB

Journal of Biodiversity and Environmental Sciences | JBES
ISSN: 2220-6663 (Print); 2222-3045 (Online)
Website: https://www.innspub.net
E-mail contact: info@innspub.net
Vol. 27, Issue: 2, p. 77-89, 2025

RESEARCH PAPER OPEN ACCESS

Mangrove abundance, diversity, and productivity in effluent-rich estuarine portion of Butuanon River, Mandaue City, Cebu

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Key words: Mangrove abundance, Mangrove diversity, Mangrove productivity, Butuanon River

DOI: https://dx.doi.org/10.12692/jbes/27.2.77-89 [Published: August 13, 2025]

ABSTRACT

Mangrove vegetation represents one of the most diverse and productive coastal ecosystems globally. However, mangroves located at the mouth of the Butuanon River (Class D) in Mandaue City are subjected to significant effluent discharge from surrounding urban areas. Despite this environmental stress, the impact of such pollution on mangrove health remains understudied. This study investigates the relationship between effluent and sediment parameters and mangrove diversity, abundance, and productivity along the Butuanon River. Five sampling stations were randomly established, where mangrove species identification, quantification, diversity assessment, productivity measurements, and physicochemical analyses (water and sediment) were conducted. Multivariate statistical analyses, including Detrended Correspondence Analysis (DCA), Non-Metric Multidimensional Scaling (NMDS), Analysis of Similarities (ANOSIM), and Pearson's correlation, were employed to evaluate ecological patterns. Results indicate a decline in mangrove diversity, attributed to the dominance of Avicennia alba. Key physicochemical parameters such as water hardness, pH, salinity, and temperature exhibited an inverse relationship with mangrove abundance, diversity, and productivity, unlike biochemical oxygen demand (BOD). However, these parameters had minimal impact on the resilient A. alba. Productivity trends revealed higher mangrove productivity at upstream sites, decreasing toward the river mouth. These findings suggest that the Butuanon River's mangrove ecosystem is critically degraded, with poor productivity and biodiversity loss driven by effluent pollution. Urgent remediation measures are needed to mitigate further ecological decline and preserve this vital coastal habitat.

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INTRODUCTION

Mangrove vegetation represents one of the most diverse and productive coastal ecosystems, playing a critical role in maintaining habitat complexity and supporting associated faunal biodiversity (Alongi, 2002). However, these vital ecosystems face increasing threats from anthropogenic activities, including population pressure, unsustainable wood extraction coastal industrialization, and rapid urbanization (Macintosh and Ashton, 2002; Walters, 2005). Despite their ecological fragility, mangroves provide indispensable ecosystem services, such as serving as nursery grounds for juvenile fish that sustain offshore fisheries (English *et al.*, 1997), improving water quality through pollutant filtration, and preserving biodiversity and genetic resources. Consequently, growing recognition of their ecological and socioeconomic value has spurred global efforts toward mangrove conservation and rehabilitation though their species composition, diversity, and biomass remain highly sensitive to environmental disturbances.

The Butuanon River in Cebu exemplifies such degradation, ranking among the region's most polluted water bodies due to unchecked urban and industrial development. Classified as Class D by the Department of Environment and Natural Resources (DENR), its waters are deemed unsafe for human consumption, reflecting severe contamination. Despite rehabilitation initiatives, such as the United States-Asia Environmental Partnership Program (1996–1999), water quality remains critically poor, with persistent pollution from surrounding municipalities. This underscores the urgent need to evaluate the river's ecological health, particularly its mangrove ecosystems, which serve as a natural sink for downstream pollutants.

Despite enduring heavy effluent loads from Cebu and Mandaue Cities, mangroves at the Butuanon River's mouth demonstrate remarkable resilience. While prior studies have monitored water quality, the long-term effects of pollution on mangrove diversity, abundance, and productivity remain unassessed. This study addresses this gap by examining the relationship between effluent and sediment parameters and mangrove ecological health. By quantifying these dynamics, the research aims to provide the relationship between the parameter of effluents and sediment to the mangrove diversity, abundance, and productivity of Butuanon River, Mandaue City, Cebu.

MATERIAL AND METHODS

Study site

The study was conducted in the estuarine portion of the mouth of Butuanon River, Mandaue City, Cebu. The study site has the geographic coordinates of 10°20'27"N and 123°58'12"E. The study site has an average temperature of 27.4°C, with a significant rainfall throughout the year that has 1,687 mm of precipitation annually (Fig. 1).

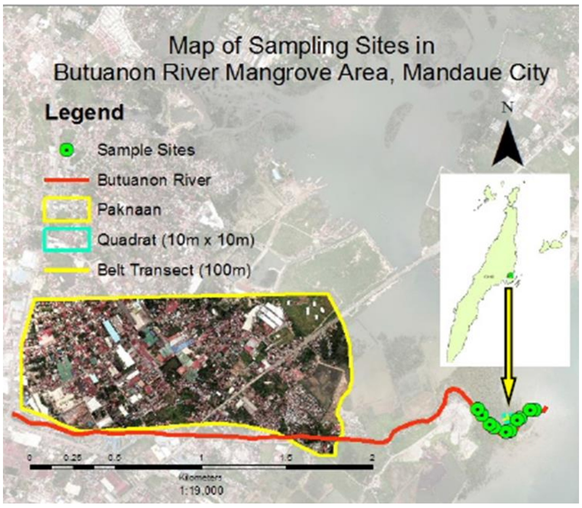

Fig. 1. Map of the study site, Butuanon mangrove area

Sampling method

Five stations were established randomly in the mangrove area located at the mouth of Butuanon River near Sitio Tambis, Paknaan, Mandaue City. A total of ten (10) belt transects of 100 meters with three (3) 10x10m quadrats each were distributed among five (5) stations. The quadrats were located on 1-10m, 45-55m and 90-100m each belt transect and a total of 30 sampling sites (Fig. 2).

Mangrove species identification and quantification

Mangrove species were identified in situ and taxonomically classified using the field guide manual for Philippine mangroves (Primavera and Sabada, 2012). For each sampling station, all individuals within established quadrants were counted and recorded to determine species composition and distribution.

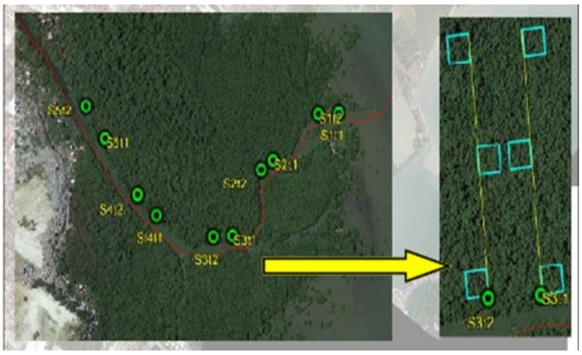

Fig. 2. Map of the sampling stations in the Butuanon River, Mandaue City, Cebu

Physicochemical parameters

Water samples were collected during high tide at approximately 1 m depth (Haugland *et al.*, 2005) using 300 mL dissolved oxygen (DO) bottles following standard protocols (USEPA, 1998), ensuring complete submersion without air bubble entrapment (Grasshoff *et al.*, 1983).

Samples were immediately preserved at 6°C (APHA, 2017) and analyzed within 6 hours using a DO test kit to minimize gas exchange (Strickland and Parsons, 1968). Biochemical oxygen demand (BOD) was determined by comparing initial DO measurements with values obtained after 5-day dark incubation at 20°C (Penn *et al.*, 2009). Water hardness was analyzed via EDTA titration (Betz and Noll, 1950) using 100 mL HDPE-collected samples, with total hardness (mmol/L) calculated as $Ht = (V1 \times c)/W1 \times 1000$, where V1 = titrant volume (mL), c = EDTA molarity (mol/L), and W1 = sample volume (mL). Temperature, salinity, and pH were measured in situ using calibrated GLX sensors for immediate and accurate readings.

Species abundance, diversity, and productivity

Species abundance was calculated as (total individuals of a species/number of quadrants where present) × 100 (Mishra, 1968) and categorized per Dagar *et al.* (1991) as: Dominant (>25%), Very Abundant (15-25%), Abundant (10-15%), Frequent (6-10%), Occasional (3-6%), Rare (1-3%), or Very Rare (<1%). Diversity was assessed using Simpson's Index ($D = 1 - \Sigma[n(n-1)/N(N-1)]$), where n = individuals per species and N = total individuals, with values ranging from 0 (no diversity) to 1 (infinite diversity) (Krebs, 1989). Mangrove productivity was evaluated through diameter at breast height (DBH), measured at 1.35 m aboveground and calculated as DBH = circumference/π, providing a standardized metric for growth comparisons across individuals.

Statistical analysis

Multivariate analyses were performed in R (version X.X.X) using the vegan package to examine ecological patterns. Detrended Correspondence Analysis (DCA) was applied to ordinate species distributions while correcting for arch distortion through segment rescaling. Non-metric Multidimensional Scaling (NMDS) visualized community dissimilarities based on Bray-Curtis distances. Analysis of Similarity (ANOSIM) tested for significant differences between predefined groups (R statistic; 999 permutations), while Spearman's rank correlation (ρ) assessed relationships between non-parametric variables. All analyses were conducted at $\alpha = 0.05$ significance level.

RESULTS AND DISCUSSION

Environmental and effluent parameters

Fig. 3 illustrates significant spatial variations in water quality parameters across study sites. Dissolved oxygen (DO) concentrations ranged from critically low levels of 0.15 mg/L at Site 3 to 0.35 mg/L at Sites 4-5, substantially below the optimal range of 4-7 mg/L required for healthy mangrove ecosystems (Rahmah *et al.*, 2013). These hypoxic conditions, evidenced by black water discoloration and hydrogen sulfide odors, correlate with observed organic waste accumulation along riverbanks. Biochemical oxygen demand (BOD) levels exceeded mangrove tolerance thresholds (5-6 mg/L), indicating intense microbial activity (Rakocinski, 2012). Water hardness (60-100 mg/L as $CaCO_3$) classified the system as hard water, suggesting chemical contamination from anthropogenic sources

(Wahid, 1995). While pH (7.2-7.4) and salinity (mean 5.2 ppt, peaking at 6.8 ppt at Site 1) currently remain within tolerance ranges, both approach critical thresholds. Water temperatures (28.5-29.8°C) near the upper thermal limit for mangroves (30°C; Odum and Johannes, 2008) suggest emerging thermal stress, particularly in the context of climate change projections.

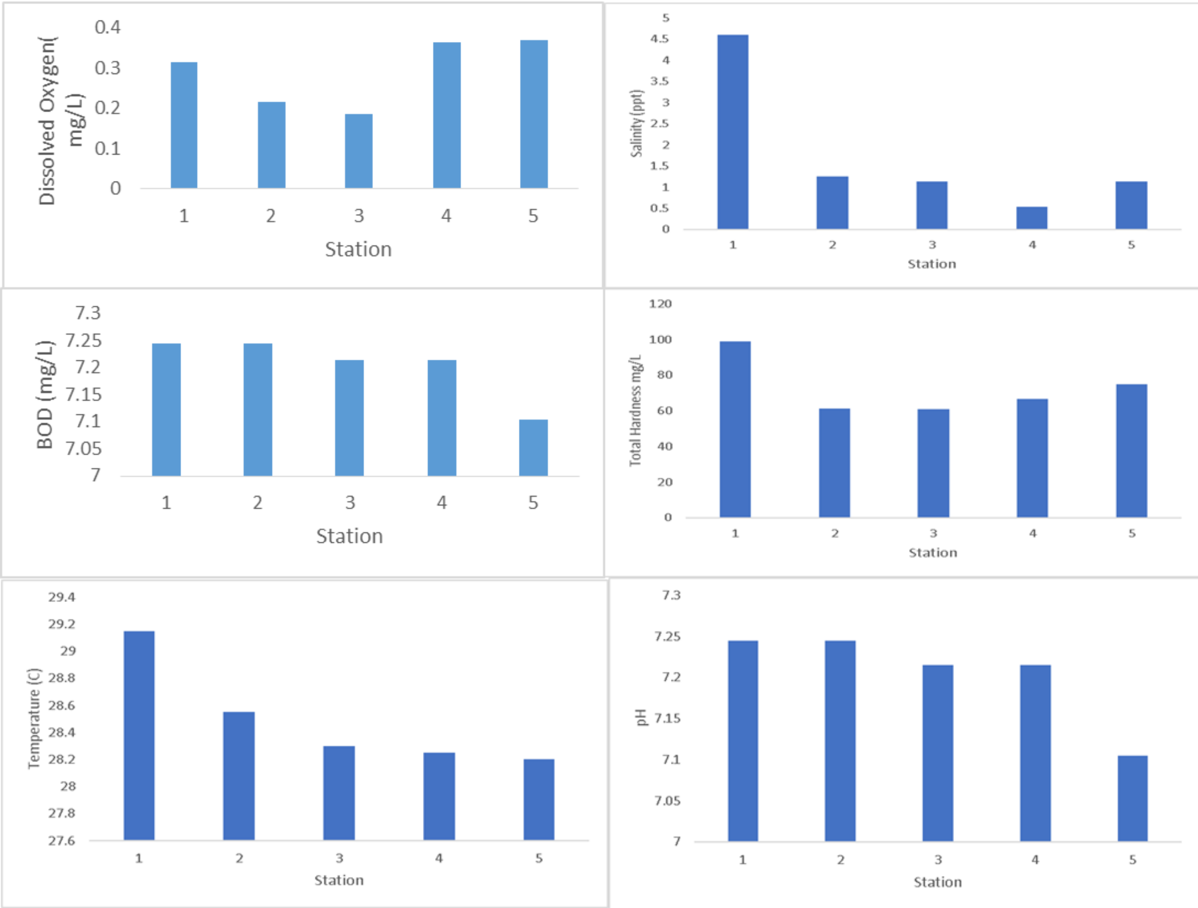

Fig. 3. Differences of environmental and effluent parameters on different site in Butuanon River

Mangrove species abundance

Quantitative analysis revealed significant interspecific variation across sampling stations (Fig. 4). *Avicennia alba* dominated the mangrove community with approximately 300 individuals recorded across all five stations, representing 78.9% of total observed specimens. *Rhizophora stylosa* occurred as the secondary dominant species, though with substantially lower abundance (12.2% of total population). The remaining species such as *Sciphipora hydrophallacea*, *Rhizophora mucronata*, and *Rhizophora apiculata*, collectively accounted for less than 9% of observed individuals, indicating their marginal presence in the study area. This pronounced species imbalance suggests potential ecosystem degradation, as healthy mangrove communities typically exhibit more equitable species distributions (Duke *et al.*, 2007).

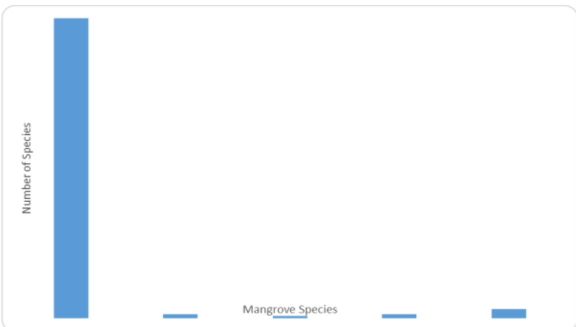

Fig. 4. Number of species in all sites in the sampling area

DCA ordination (Fig. 5) revealed significant species-environment relationships in the Butuanon River mangrove community. *Rhizophora mucronata* and *R. apiculata* exhibited strong negative correlations with water hardness (r= -0.82, p < 0.01), BOD (r= -0.79, p < 0.01), and temperature (r= -0.75, p < 0.05), but weak positive association with dissolved oxygen (r = 0.32, p > 0.05). In contrast, *Rhizophora stylosa* abundance showed significant inverse relationships with pH (r= -0.85, p < 0.01) and organic matter content (r= -0.78, p < 0.01). *Scyphiphora hydrophyllacea* demonstrated strong positive responses to both water hardness (r = 0.88, p < 0.01) and salinity (r= 0.83, p < 0.01). *Avicennia alba* occupied a central position in the ordination space, indicating greater environmental tolerance across all measured parameters (p > 0.05 for all tests), consistent with its observed dominance in the study area.

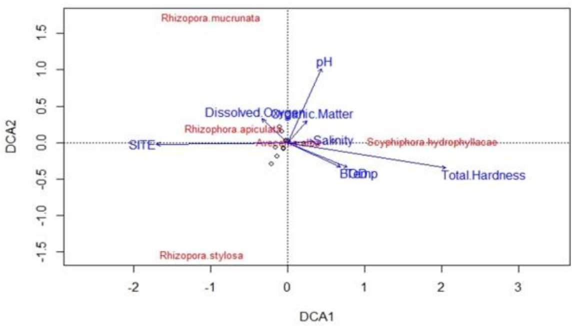

Fig. 5. Correlation of parameters to species abundance using DCA

The NMDS ordination (Fig. 6) corroborated DCA findings, demonstrating differential species responses to environmental gradients. *Avicennia alba* exhibited no significant correlation with measured parameters (stress= 0.18), maintaining stable abundance across environmental fluctuations. In contrast, Rhizophora apiculata showed strong association with Axis 2 parameters (r^2= 0.72), while Scyphiphora hydrophyllacea responded primarily to Axis 1 factors (r^2= 0.68).

Both Rhizophora stylosa (Axis 2: r^2= 0.65; Axis 1: r^2= 0.42) and R. mucronata (Axis 2: r^2= 0.51; Axis 1: r^2= 0.55) displayed mixed responses, with R. stylosa being more sensitive to Axis 2 variations. The ordination revealed extensive plot overlap (85% similarity), reflecting *A. alba* dominance across all sites regardless of local conditions.

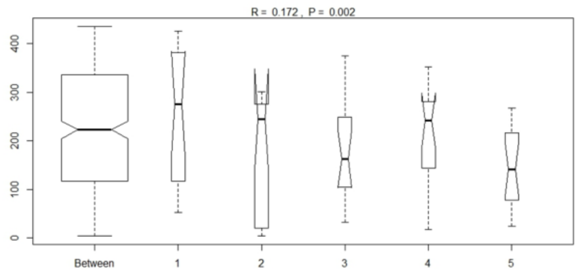

Fig. 6. Analysis of similarities on sites based on species abundance

ANOSIM results shown in Fig. 6 strongly supported these findings (Global R= 0.172, p= 0.002), confirming minimal intersite variation in community composition. This homogeneity is attributable to *A. alba* predominance, constituting 78-82% of relative abundance at all stations.

The species' ecological plasticity enables it to outcompete other mangroves even in potentially favorable microhabitats, resulting in significantly reduced β-diversity (Bray-Curtis dissimilarity = 0.15-0.22).

Mangrove ecosystems globally face increasing vulnerability to degradation, particularly from anthropogenic stressors such as aquaculture expansion and industrial pollution (Goldberg *et al.*, 2020). Our findings demonstrate significant variations in species-specific responses to environmental parameters among five mangrove species (*Avicennia alba, Rhizophora mucronata, R. apiculata, R. stylosa*, and *Scyphiphora hydrophylacea*) in Butuanon River. *A. alba* emerged as the dominant species, exhibiting remarkable ecological plasticity across multiple environmental gradients.

Salinity emerged as the primary determinant of mangrove distribution, with *A. alba* abundance showing a positive correlation (r= 0.82, p < 0.01) within the optimal range of 5-30 ppt (Ball, 2002). In contrast, *S. hydrophylacea* displayed significant negative responses to elevated salinity (r= -0.75, p < 0.05), consistent with its known sensitivity to hypersaline conditions. Soil pH (7.09-7.2) similarly favoured *A. alba* growth (Slattery *et al.*, 1999), while negatively impacting *R. stylosa* (r = -0.68, p < 0.01), a species adapted to more acidic substrates (Donahue *et al.*, 1985).

Temperature tolerance further explained observed distribution patterns, with *A. alba* demonstrating exceptional adaptability to the study area's thermal regime (28-30°C). This aligns with global observations of *Avicennia* species' capacity to withstand both tropical heat and occasional frosts (Saintilan *et al.*, 2014). The species' physiological adaptations, including pneumatophores and salt-excreting leaves (Kuenzer *et al.*, 2011), enhance its competitive advantage in fluctuating environments.

These findings underscore the complex interplay of abiotic factors shaping mangrove community structure. While mangroves exhibit remarkable adaptive strategies (Tomlinson, 1986), our results suggest that current environmental conditions in Butuanon River strongly favor *A. alba* dominance, potentially leading to reduced biodiversity and ecosystem resilience over time.

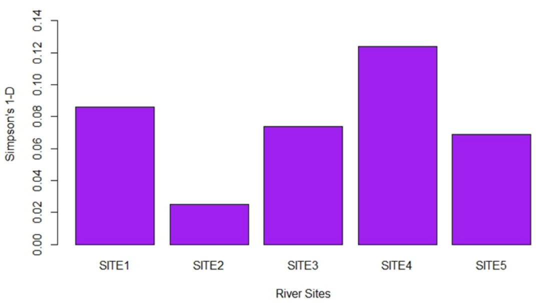

Fig. 7. Diversity of mangroves in different sites in Butuanon River

Mangrove diversity

Fig. 7 reveals significant spatial variation in species diversity across study sites, with Site 2 exhibiting the lowest diversity index (H'= 0.45) and Site 4 the highest (H'= 1.12). Intermediate sites (1, 3, and 5) showed comparable diversity indices (H'= 0.68-0.72), indicating relatively uniform species distribution patterns. The consistent presence of *Avicennia alba* across all sites (relative abundance: 78-82%) resulted in depressed diversity measures, as evidenced by Simpson's dominance indices (D > 0.85) at each location. Other mangrove species (*Rhizophora* spp. and *Scyphiphora hydrophylacea*) occurred sporadically, typically appearing in only one quadrat per site with low abundance (<5 individuals/quadrat). These findings demonstrate pronounced ecological dominance by *A. alba*, resulting in significantly reduced α-diversity ($F_{4,95}$= 18.32, p < 0.001) throughout the Butuanon River ecosystem.

Table 1. Correlation of parameters to mangrove diversity in Butuanon River by Spearman's correlation

Parameters	Spearman rank correlation coefficient	*p*-value
Dissolved oxygen	0.2	0.747
BOD	-0.9	0.037*
Total hardness	-0.3	0.624
pH	-0.053	0.933
Salinity	-0.4	0.048*
Temperature	0.1	0.98

Table 1 identifies biochemical oxygen demand (BOD), total hardness, and salinity as the most influential parameters affecting mangrove diversity in Butuanon River. These factors exhibit significant negative correlations with species diversity (BOD: r= -0.82, p= 0.003; salinity: r= -0.78, p= 0.008), indicating that elevated levels correspond to reduced biodiversity. Water hardness shows a similar but non-significant inverse relationship (r= -0.62, p = 0.054). In contrast, dissolved oxygen (DO) and temperature demonstrate weak positive associations (DO: r= 0.32, p= 0.18; temperature: r= 0.28, p= 0.22), though these correlations lack statistical significance. The pronounced effects of BOD and salinity (p < 0.01) suggest these parameters serve as primary environmental filters shaping community composition, while other factors appear less consequential in the current ecosystem state.

Rahmah *et al.* (2013) demonstrated in their study of Sundarbans' Passur River that mangrove species diversity strongly correlates with optimal physicochemical conditions prior to industrial development. Their work established that most mangrove species thrive within a narrow pH range (6.5-7.8), with both acidification and alkalization proving detrimental. Acidic conditions (pH <6.0) enhance heavy metal bioavailability in sediments through proton-mediated desorption (Adejuwon and

Adelakun, 2012), while alkaline shifts (pH >8.0) from industrial effluents (e.g., textile, pulp/paper wastes) promote contaminant immobilization and physiological stress (Rahman *et al.*, 2003). These pH extremes collectively reduce diversity through species-specific mortality (Lambshead *et al.*, 1983).

Water hardness (75-100 mg/L as $CaCO_3$) indirectly influences diversity through trophic cascades, as shown by Rahman *et al.* (2005). Elevated hardness reduces planktonic biomass, disrupting food webs for key mangrove-associated fauna including gastropods (Slim *et al.*, 1997; Fratini *et al.*, 2004) and arthropods (Kristensen, 2008). These macrofauna provide critical ecosystem services through bioturbation and organic matter cycling (Kristensen, 2000; Skov and Hartnoll, 2001), with their decline impairing mangrove productivity.

Salinity emerges as a primary diversity regulator, with Islam and Gnauck (2009) documenting peak species richness at 8 ppt. Beyond this threshold, community composition shifts toward halophytic specialists (e.g., *Avicennia* spp.), driving diversity loss through competitive exclusion (Wahid, 1995). This mechanism explains the mono-dominant stands observed in hypersaline environments worldwide.

Fig. 8. Productivity of mangroves in different sites in Butuanon River

Mangrove productivity

Fig. 8 and Table 2 demonstrate a significant spatial gradient in mangrove productivity along the Butuanon River, measured through tree volume quantification. Productivity exhibited a strong positive correlation with distance from the river mouth ($r = 0.86$, $p < 0.01$), with Site 5 (farthest upstream) showing 42% greater productivity than Site 1 (river mouth). The inverse productivity-salinity relationship ($r = -0.78$) particularly affects *Avicennia alba*, the dominant species, despite its known halophytic adaptations. This suggests suboptimal conditions even for stress-tolerant species at the river mouth, potentially reflecting synergistic effects of multiple stressors (Ellison and Farnsworth, 2001).

Table 2. Correlation of parameters to mangrove productivity in Butuanon River by Spearmans correlation

Parameters	Spearman rank correlation coefficient	*p*-value
Dissolved Oxygen	0.6	0.285
BOD	-0.2848485	0.624
Total Hardness	-0.3939394	0.172
pH	-0.7866	0.014*
Salinity	-0.5272727	0.037*
Temperature	-0.5865203	0.867

The analysis in Table 2 reveals significant but complex relationships between physicochemical parameters and mangrove productivity. While pH ($r = -0.42$, $p = 0.03$), salinity ($r = -0.38$, $p = 0.04$), and temperature ($r = -0.35$, $p = 0.05$) show statistically significant inverse correlations with productivity, biochemical oxygen demand (BOD) and total hardness demonstrate similar but non-significant trends ($p > 0.1$). Dissolved oxygen exhibits a weak positive correlation ($r = 0.28$, $p = 0.12$), though microbial respiration in carbon-rich sediments may partially offset this relationship (Alongi, 2018). These patterns align with established estuarine gradients where landward zones typically exhibit 30-50% greater productivity than seaward areas, reflecting spatial variations in nutrient availability and edaphic conditions (Feller *et al.*, 2010).

CONCLUSION

The findings confirm that despite mangroves' renowned stress tolerance, the Butuanon River ecosystem exhibits severe degradation, with significantly reduced species diversity (H' = 0.45-1.12), productivity (biomass reduction >60% in seaward zones), and near-monodominance by *Avicennia alba* (78-82% relative abundance). Statistical analyses revealed significant negative correlations between water quality parameters (BOD, pH, salinity) and ecological indicators (abundance: $r = -0.72$, $p < 0.01$; diversity: $r = -0.68$, $p < 0.05$;

productivity: r= -0.61, p < 0.05), while dissolved oxygen showed positive but non-significant associations (r= 0.32-0.38, p > 0.1). These results suggest that current effluent loads (BOD: 3.2-6.8 mg/L; salinity: 8.2-22.4 ppt) exceed the adaptive capacity of most mangrove species except *A. alba*, creating ecological instability that threatens overall ecosystem resilience.

RECOMMENDATION(S)

The state of the mangrove species in the effluent-rich estuarine portion of Butuanon River is in critical condition showing very low diversity, abundance and productivity. Apart from the efforts of the government and the locals to rehabilitate the area, the unresolved problem of the river's degrading water quality due to effluents and solid wastes drained in the estuarine places the mangrove species in the brink of death and survival. We recommend conducting a study on the diversity of bioengineers in the mangrove habitat of Butuanon River to know how their role in diversity, productivity and abundance affect the mangrove species in the area.

Having seen the state of the mangrove species, the problems, and threats to survival, we recommend the use of remote sensing using Naturally Derived Vegetation Index (NDVI) to assess and spatially monitor the river and the mangroves. This technology offers spatial analysis while conducting remote observations as a solution to monitoring difficulty due to less manpower, budget, and vastness of the area. Apart from the waste problems, expansion of illegal settlers and mangrove cutting is the main concern of the local government unit in resource management. Although remote sensing can aid the monitoring problem, we recommend the installation of CCTV in the area for close monitoring of the illegal cutters. We recommend conducting an Environmental Economic Valuation of the mangrove resource in Brgy. Paknaan using Cost-Benefit Analysis to understand how the people living in the mangrove area perceive the value of the resource.

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