WOMEN SHELLFISHERS AND FOOD SECURITY

Assessment of Shellfish Species Diversity and Land Cover at Mangrove Restoration Sites within the Densu Delta Ramsar Site, Ghana

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Cover photo: Shellfish species at Mangrove Restoration Sites within Densu Delta Ramsar Site

Photo credit: **West Africa** Shellfish Knowledge and Outreach Hub-, Centre for Coastal Management, University of Cape Coast

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TRY	https://www.facebook.com/TRYoysters/
DAA	https://daawomen.org/

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ACRONYMS

CCM	Centre for Coastal Management
CRC	Coastal Resources Center
DAA	Development Action Association
DOPA	Densu Oyster Pickers Association
GIS	Geographic Information Systems
ICRAF	World Agroforestry (International Centre for Research in Agroforestry)
LULC	Land Use Land Cover
SFMP	Sustainable Fisheries and Management Project
TRY	TRY Oyster Women's Association
UAV	Unmanned Aerial Vehicle
UCC	University of Cape Coast
URI	The University of Rhode Island
USAID	United States Agency for International Development
WoRMS	World Register of Marine Species
WSFS	Women Shellfishers and Food Security project

EXECUTIVE SUMMARY

This report presents the findings of a baseline study of land cover and shellfish species diversity conducted in January 2024 at two mangrove restoration sites within the Densu Delta; one site (Site 1) replanted in 2017 as part of the USAID/Ghana Sustainable Fisheries Management Project (SFMP) and another site (Site 2) replanted in 2023 through the USAID Women Shellfishers and Food Security project (WSFS). These restoration efforts were aimed at enhancing shellfish production to support the livelihoods of women shellfish harvesters and provide other ecological benefits. The Centre of Coastal Management of the University of Cape Coast conducted the baseline biodiversity assessment using various methods, including land cover surveys, shellfish sampling, and data analysis to establish baselines and inform future assessments of mangrove restoration impacts on shellfisheries biodiversity. Key findings from the land cover survey revealed that Site 1 predominantly consisted of mangrove cover, which accounted for the majority (59.4%) of the land cover in the 18 sampled quadrants. In contrast, Site 2 was dominated by grass cover (45.8%), with significantly less mangrove coverage (3.1%). Results of the current study show that the differences in land cover at the two sites may have considerable bearing on the development and diversity of the shellfish community at each of these sites. Seven shellfish species were encountered at Site 1, whereas Site 2 had four species. The purple mangrove crabs and hermit crabs were observed at Site 1 only. The West African mangrove oysters were found on the roots of the replanted mangroves at Site 1, where they constitute nearly 50% of the shellfish community with the highest mean density of 170 oysters per square meter. The overall higher species diversity and richness at the Site 1 compared to the newly planted Site 2, and the larger mean size of mud creepers at Site 1 compared to Site 2, is a function of time as the mangrove trees at Site 1 planted in 2017 have grown larger thereby providing habitat for expanded biodiversity. These findings highlight the benefits of the Densu Oyster Pickers Association's (DOPA) mangrove reforestation efforts for improving the Densu Delta's ecosystem and shellfisheries productivity, which eventually can result in improved food security and livelihood, among others. It is expected that shellfish diversity at Site 2 will also increase with time as the mangrove trees grow larger, and this will be confirmed through future monitoring. Most importantly, these observations provide a baseline for monitoring the development of replanted mangroves and changes in the land cover and shellfish fauna biodiversity over time.

1. INTRODUCTION

1.1 Activity Background

Mangrove vegetation supports productive fisheries, biodiversity, shoreline protection and stabilization, maintenance of water quality, filtration of pollutants, and carbon sequestration, among other ecosystem services. Mangrove and estuarine systems are inseparably linked to the health of shellfish resources that provide livelihoods and food security for communities that depend on them. In many West African countries, shellfishery dependent populations are dominated by women shellfishers (Chuku et al., 2022). This is the case of the Densu Delta. A recent study by Chuku et al. (2022) on estuarine and mangrove-based shellfisheries in West Africa underscored the importance of the mangrove systems (i.e., over 1.5 million ha of mangrove coverage) in producing over 300,000 mt of shellfish valued at more than USD 300 million. The study, in addition to others (Dayal et al., 2022; Lee et al., 2014; Osei et al., 2021), highlighted the need for the reforestation of depleted mangrove vegetation to rebuild the shellfish stocks and sustain the livelihoods of fishers, as well as provide other ecological services. In this regard, the USAID Women Shellfishers and Food Security project seeks to foster the adoption and scaling-up of an integrated approach to conservation and restoration of mangrove and estuarine ecosystems in West Africa that provides cross-sectoral benefits in terms of gender equality and women's empowerment, economic development, and household food resiliency.

There is generally an active and unregulated exploitation of mangrove vegetation across the West African sub-region (Chuku et al., 2022), which impacts the biodiversity and productivity of coastal water bodies, including estuaries and lagoons. Over the last 50 years, degradation and deforestation of mangrove vegetation have destroyed 20–35 percent of global mangrove cover (Polidoro et al. 2010). Ghana's mangrove forest is declining at a rate of 8.1 km^2 per annum due to over-cutting, land conversion, wildfires, pollution, overgrazing, and natural death from disease (Nunoo & Agyekumhene, 2022). Between the years 2000 and 2010, Ghana's mangrove cover significantly declined from 118,546 ha to 42,690 ha, mainly as a result of clearing for settlement and other urban activities, fuel wood collection, construction, among others (Duguma et al., 2022). Not only did the loss of Ghana's mangroves reduce the coastal forest cover and its consequent blue carbon sequestration functions, but it also significantly affected coastal and marine biodiversity and fishery-based livelihoods, especially the mangrove-based oyster fisheries, which are exploited predominantly by women in coastal communities of Ghana.

To reverse the trend and improve mangrove cover and associated livelihoods, the Women Shellfishers and Food Security project planned an ambitious mangrove restoration activity at the Densu Delta Ramsar site, which was one of the management measures in the Densu co-management plan, to be carried out by the Densu Oyster Pickers Association (DOPA). DOPA initiated efforts to restore the degraded mangroves in the Densu Delta Ramsar site through the support of the USAID-funded Sustainable Fisheries Management Project (SFMP) in 2017. Through this initiative, DOPA was able to lead the nursing and transplanting of 3,900 mangrove seedlings between 2017-2018 covering 14.67 ha. In 2023, DOPA nursed and transplanted an additional 4,500 seedlings covering 12.40 ha through the support of the WSFS Project. The project will continue this support in 2024 and 2025. DOPA aims to institute mangrove restoration as an annual event carried out in the Densu Delta depending on future support.

Observations from a site visit by DOPA and women shellfishers in 2023 showed that oysters had begun colonizing the roots of the SFMP site (2017), Site 1 mangroves, suggesting that the efforts of DOPA are culminating into gradual ecological and biodiversity gains. However, the absence of baseline data and systematic assessment and documentation of the gains in biodiversity and ecosystem services is currently limiting the available evidence-base for stakeholder support and scaling. This biodiversity assessment was therefore carried out to provide baseline data on the diversity of shellfish species at the previously (Site 1-2017) replanted mangrove site and the newly (Site 2-2023) replanted mangrove site within the Densu Delta, also including floral diversity and coverage. This study serves as a baseline for monitoring and comparison for future appraisals that can be conducted to update the status and trends of floral and shellfish biodiversity in the Densu Delta.

2. METHODS

2.1 Study Locations

The shellfish biodiversity assessment was carried out in the Densu Delta, located between longitudes 0° 16' W - 0° 21' W and latitudes 5° 30' N - 5° 33' N. The Delta is fed by a river that originates from the Atewa Mountains in the East Akim Abuakwa District of the Eastern Region of Ghana (Oteng-Yeboah, 1999). The river has been dammed at Weija (a nearby town) to produce potable water for some areas in the Greater Accra Region of Ghana (Figure 1). The Delta is greatly influenced by water spillage from the Weija Dam during high precipitation. Some of the species harvested by local residents include oysters, crabs, mud-flat periwinkles, shrimps, flat sardinella, and black-chinned tilapia. The finfish are exploited predominantly using cast nets and drag nets, whereas the shellfish are harvested mainly through handpicking and the deployment of baited traps.

2.1.1 Study sites and sampling points

Through the intervention of the Women Shellfishers and Food Security project, DOPA planted mangrove seedlings in a 12.40 ha area of the Densu Delta in April 2023 to improve the biodiversity of the delta as well as enhance shellfisheries productivity (Figure 2). Previously, the SFMP supported mangrove planting in 2017, with mangrove seedlings covering approximately 14.67 ha, as seen in Figure 2. The Centre for Coastal Management, University of Cape Coast, assessed shellfish biodiversity at both mangrove-replanted sites, namely the SFMP Site 1 (2017) and the Women Shellfishers and Food Security Site 2 (2023), as indicated in Figure 2. Sampling areas at both sites were selected along the course of the water to cover the shellfish species that inhabit the different niches with the system – i.e. the water, the water banks and the mangrove. Three line transects covering an area of about 7,200 m^2 were laid, as demonstrated in the map. Each transect covered an area of 2,400 m^2. On both sites, transect 1 was laid close to or at the watermark, whereas Transects 2 and 3 were laid landward, respectively. Resources constrained the ability to include a non-forested control site and to spread out the sampling more.

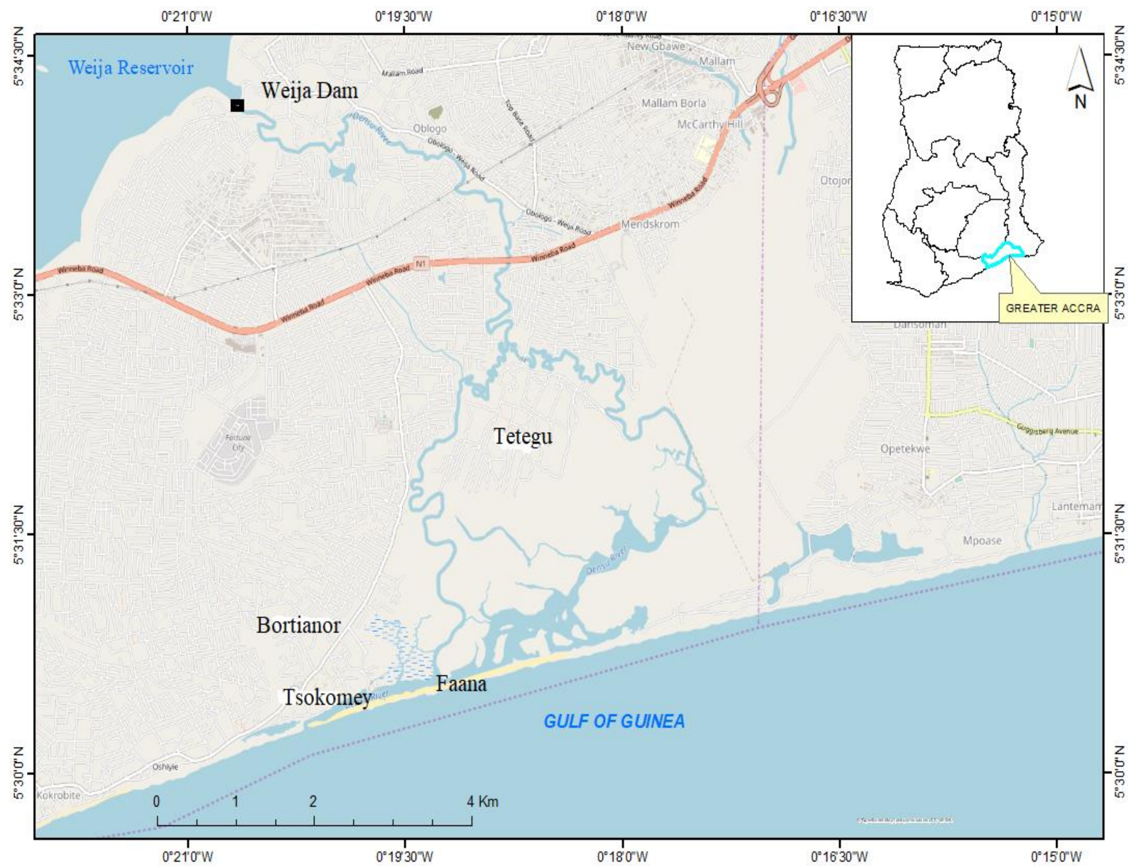

Figure 1: Map of Ghana, showing the study location, Densu Delta, and the location of the Weija Dam.

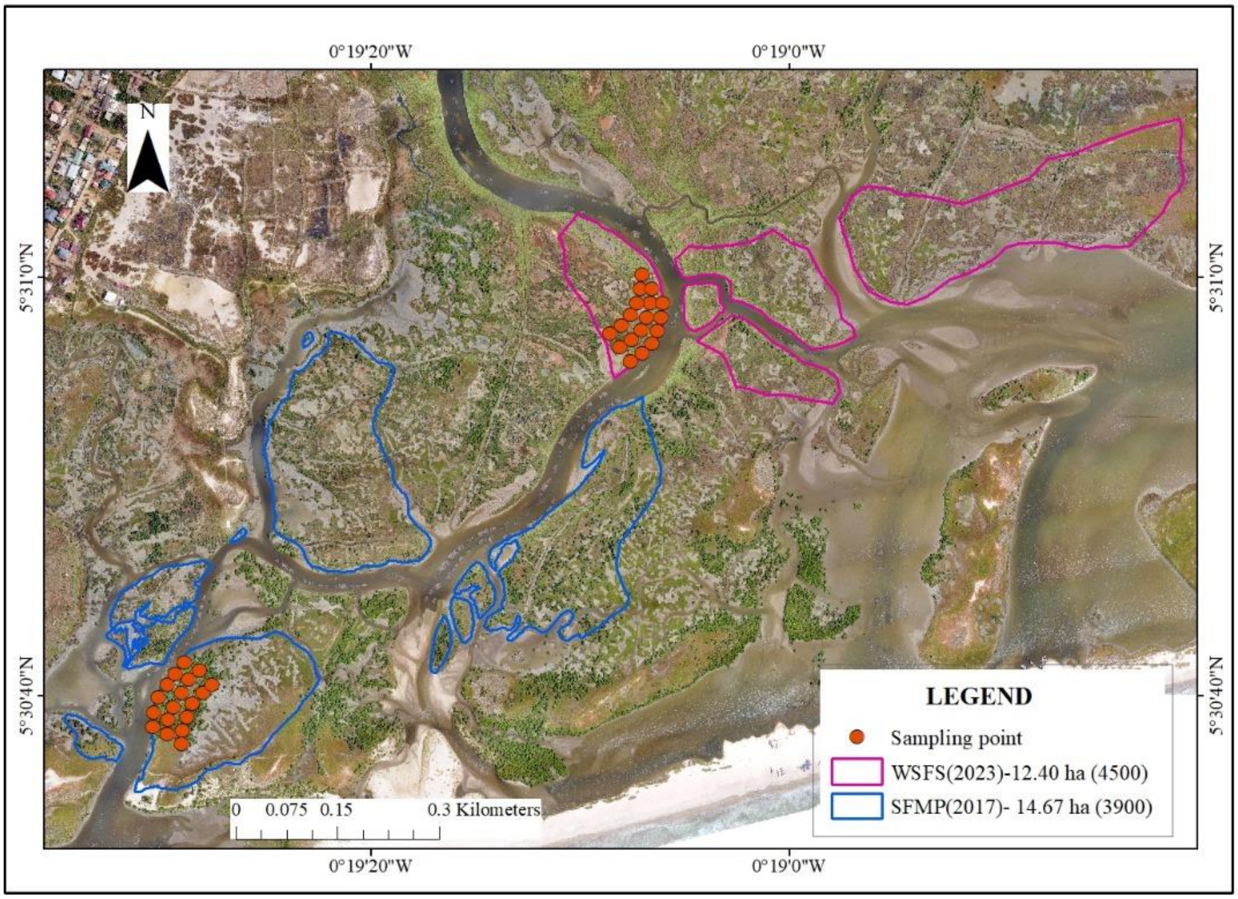

Figure 2: Map of the Densu Delta, Ghana, showing the study sites and sampling points.

2.2 Data Collection

2.2.1 Land cover survey

The team conducted a rapid assessment to evaluate the ecological state of the Densu Delta in January 2024. Two sites covering about 10,000 square meters each were randomly selected for the study from both old and newly restored mangrove areas (Figure 3). Each site was further divided into 18 sampling areas, each measuring 20 m x 20 m, starting from the riverbanks and extending into the mangrove stands. Vegetation cover was assessed within the (20 m x 20 m) grids to gather data on the different vegetation types.

2.2.2 Land cover mapping

The team mapped land cover within the 18 sampling areas in the study sites (Figure 3) using the C-Astral Bramor PPX Unmanned Aerial Vehicle (UAV) equipped with a Sony A6000 camera. The imagery was obtained at a nadir interval of 1.3 seconds while flying at an altitude of 150 meters above ground level and a speed of 16 meters per second. The capture involved an 80 percent overlap with an additional 70 percent side overlap.

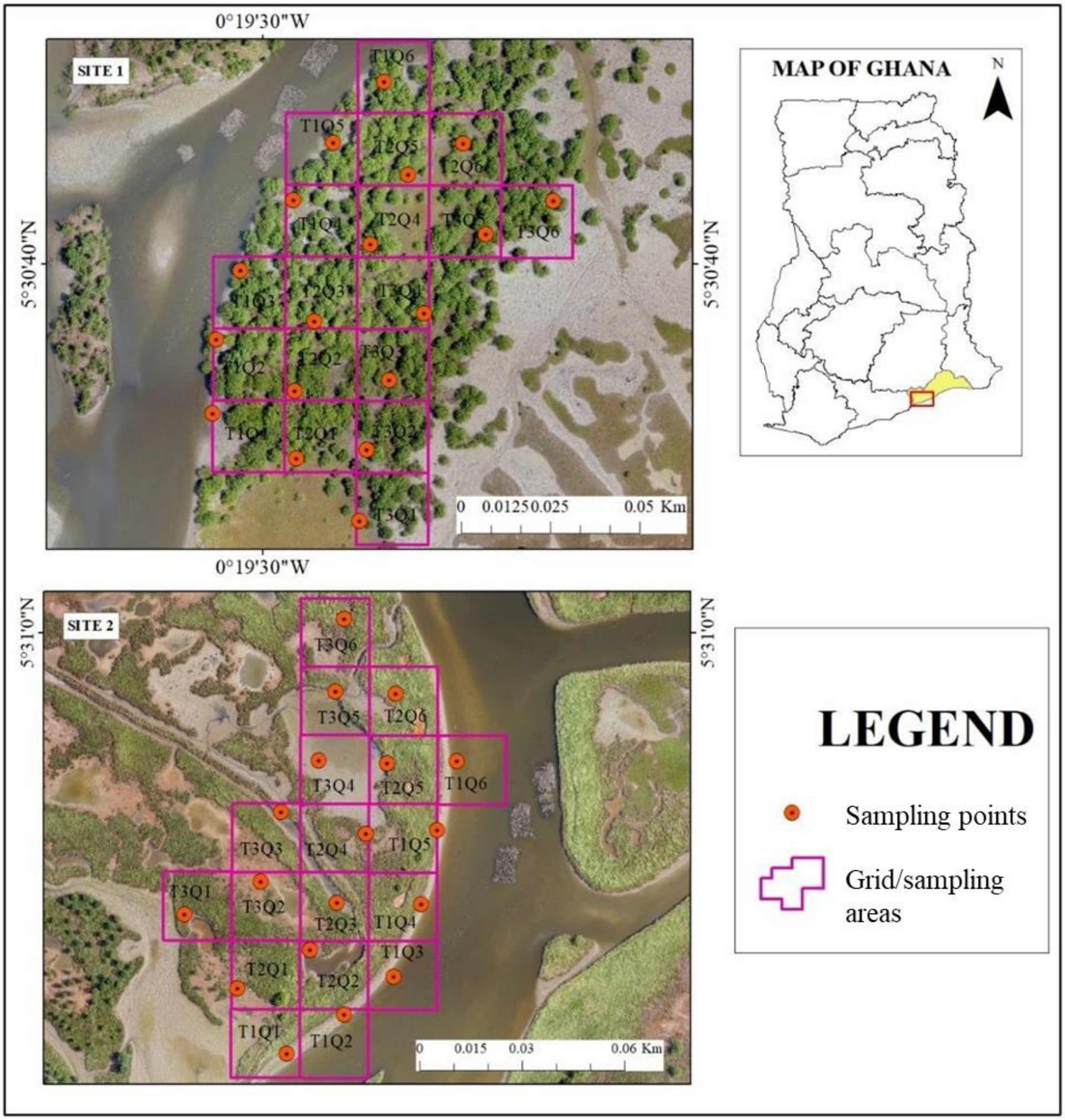

Figure 3: Map showing the selected sites, sampling areas, and sampling points (Site 1- SFMP site; Site 2- WSFS Site).

Following the mapping process, the team acquired a total of 3,042 images from two flights conducted on March 18, 2024. The team used Pix4D Mapper software version 4.1 to process all the acquired images to generate ortho-mosaicked images. The decision to utilize UAV imagery instead of satellite imagery was made due to several key factors. UAV imagery boasts significantly higher resolution, allowing for more detailed and precise data collection. Additionally, the absence of cloud cover is a critical factor in selecting UAV imagery. Moreover, opting for UAV imagery proves to be more cost-effective compared to satellite imagery. These combined factors make UAV imagery the optimal choice for the project. The orthomosaic was subjected to image classification. In the image classification process, both unsupervised and supervised classification algorithms were employed. Unsupervised classification was done to aid in the exploration of the land use/cover types. Ground-based knowledge after detailed field surveys was used to select training samples for the supervised classification. Support Vector Machine classifiers were used as the decision rule for the supervised classification algorithms and the categorization of the land use/land cover (LULC) types. Six LULC classes were categorized using their spectral and textural characteristics and their feature space. The classes were water, mangrove, grass, sand, marsh dayflower, and mud.

2.2.3 Shellfish sampling

The team conducted sampling of shellfish species in January 2024. Line transects and quadrats were used to sample shellfish at both sites. A 0.25 m^2 quadrat was placed within a 2 m x 2 m detachable quadrat along the line transect at a fixed distance (20 m) (see sampling points in Figure. 2). The 2 m x 2 m detachable quadrat was used to demarcate areas at six sampling points along the transect in the mangrove vegetation, within which the 0.25 m^2 was deployed randomly (three throws per sampling point) (Figures 3 and 4). Shellfish species within the quadrat were counted and recorded in a field notebook. Also, crab burrows within the 0.25 m^2 quadrat were counted and recorded to serve as a proxy to estimate the number of crabs within the throw.

Figure 4: Shellfish sampling using a 0.25 m^2 quadrat within a 2 m x 2 m detachable quadrat in a transect.

2.2.4 Shellfish identification and morphometric measurements

Shellfish specimens were taken, labeled, and placed in zip-lock bags for identification and morphometric measurement purposes. The team took photographs of specimens in-situ and preserved samples in 10 percent formalin and kept them sealed in a container. Species identification was carried out using Schneider (1990) and the online portal of WoRMS (World Register of Marine Species). Shell height (cm) of periwinkles were measured, using a caliper. Given that oysters were newly colonizing the roots of the replanted mangroves at Site 1, the team left oyster specimens untouched in order not to interfere with the development of the population; hence, oyster specimens were not taken to the laboratory for measurement.

2.3 Data Analyses

2.3.1 Species composition

The team analyzed overall species compositions of shellfish for each transect across Site 1 and Site 2.

2.3.2 Diversity of shellfish community

Species Diversity (Shannon-Weiner)

Species diversity was calculated using the Shannon-Weiner diversity index (H′) (Shannon & Weiner, 1949): $H' = -\sum_{i=1}^{s} pi\ In\ pi$

Where H' is the Shannon-Wiener index, *S* is the total number of species and *pi* is the proportion of each species in each sample.

Species Richness (Margalef Richness Index)

Species richness was calculated using the Margalef richness index (d) (Clarke & Warwick, 1994): $d = (S - 1)/\ln N$

Where *d* is the Margalef richness index, *S* is the total number of species and *N* is the total number of individuals.

Species Evenness

Pielou's evenness (J') (Pielou, 1966) was used to analyze the uniformity of each species in the environment (i.e., species evenness or the distribution of individuals per species) using the formula: $J' = H'/\ln S$

Where *J'* denotes Pielou's evenness, *H´* is the Shannon–Wiener index and *S* is the total number of species.

2.3.3 Similarity of the shellfish communities

The degree of similarity between communities over time was determined by Sorensen's similarity index: $C_s = [2j / (a + b)]$

Where *j* is the number of species common to the two fish communities, *a* and *b* are the number of species occurring in either of the wetlands.

2.3.4 Size-distribution of shellfish species

The team recorded the length ranges (maximum and minimum lengths) of collected species . Where sufficient samples were obtained, such as in the case of the mud creeper (*Tympanotonus fuscatus*), length distribution of the species was analyzed at 1 cm class intervals to establish their modal sizes and graphed using a histogram.

2.3.5 Density of shellfish species

The density of the shellfish was calculated by dividing the number of specimens for each species (counted in each of the 2 m x 2 m quadrat) by four to obtain the number per square meter of area. Arithmetic means and corresponding standard errors were determined for each transects.

3. RESULTS AND DISCUSSION

3.1 Land Cover

Figures 5 and 6 as well as Tables 1 and 2 provide detailed information on the extent of different land cover types in the 18 sampling areas across two sites, Site 1 and Site 2. As shown in Table 1 and Figure 6, Site 1 was characterized by prominent mangrove cover, which constituted approximately 59.4 percent of the total area surveyed. This is a significant aspect, as mangroves provide critical ecological services, including habitat and feeding grounds for coastal and marine life within the Densu Delta. The next dominant land cover type was grass, accounting for 12.0 percent of the area. Other types of cover, such as mud and water, contributed smaller proportions (8.7% and 16.9%, respectively). The area is characterized by a minimal presence of sand and no significant coverage of marsh dayflower, which contributed to 3.0 percent. In contrast, Site 2 reflects a more varied distribution of land cover types (Table 2 and Figure 6). Here, mangrove coverage was much lower (3.1%), indicating a reduction in critical mangrove habitat type for oysters compared to Site 1. However, most of the area (45.8%) was covered by grass. Additionally, water coverage in Site 2 was significantly higher (25.6%), while mud and sandy areas contributed 15.7 percent and 0.8 percent, respectively. Interestingly, leafy vegetation, which was not present in Site 1, covered about 9.1 percent, suggesting a different ecological composition within the two sites.

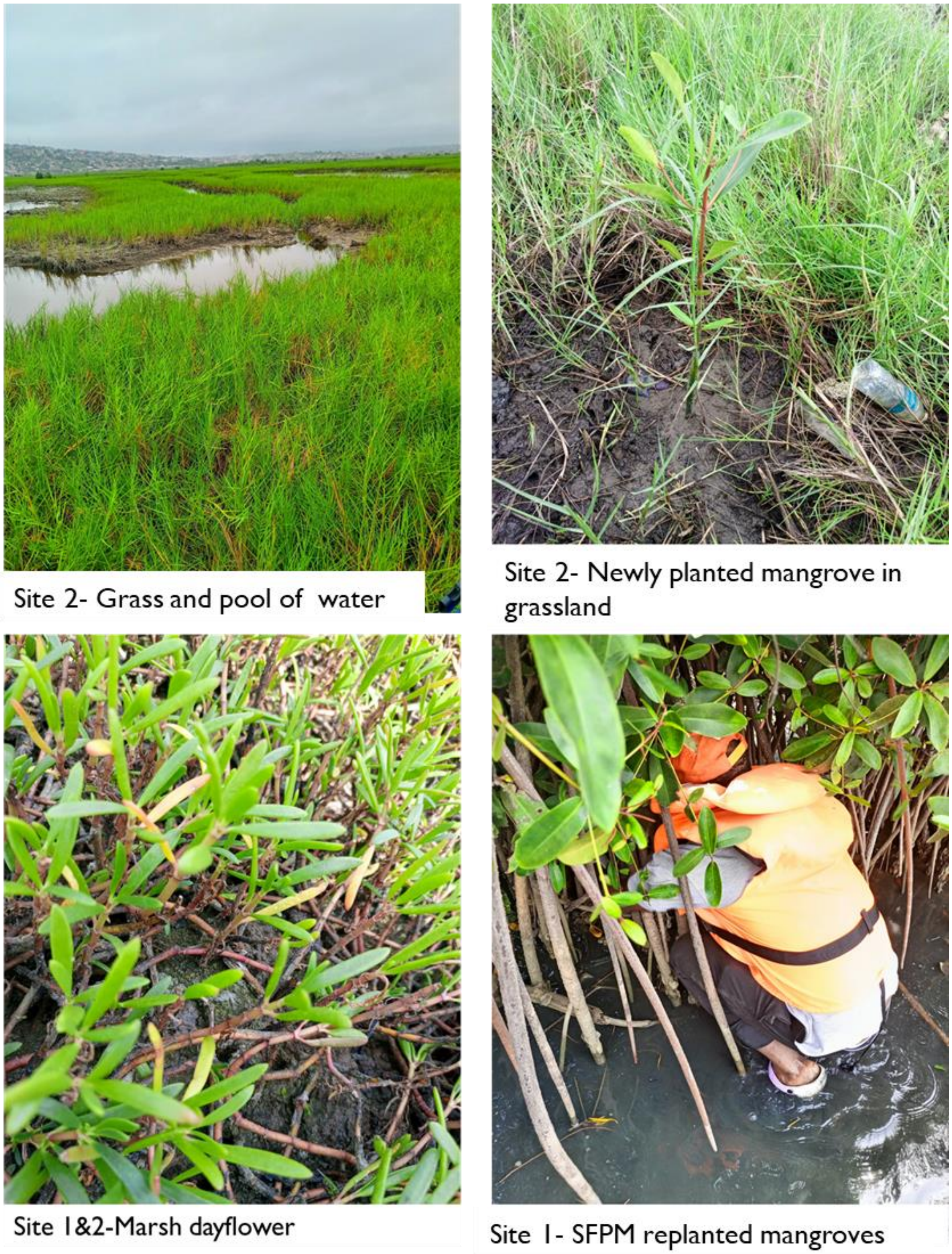

Figure 5: Various forms of land cover at the study sites.

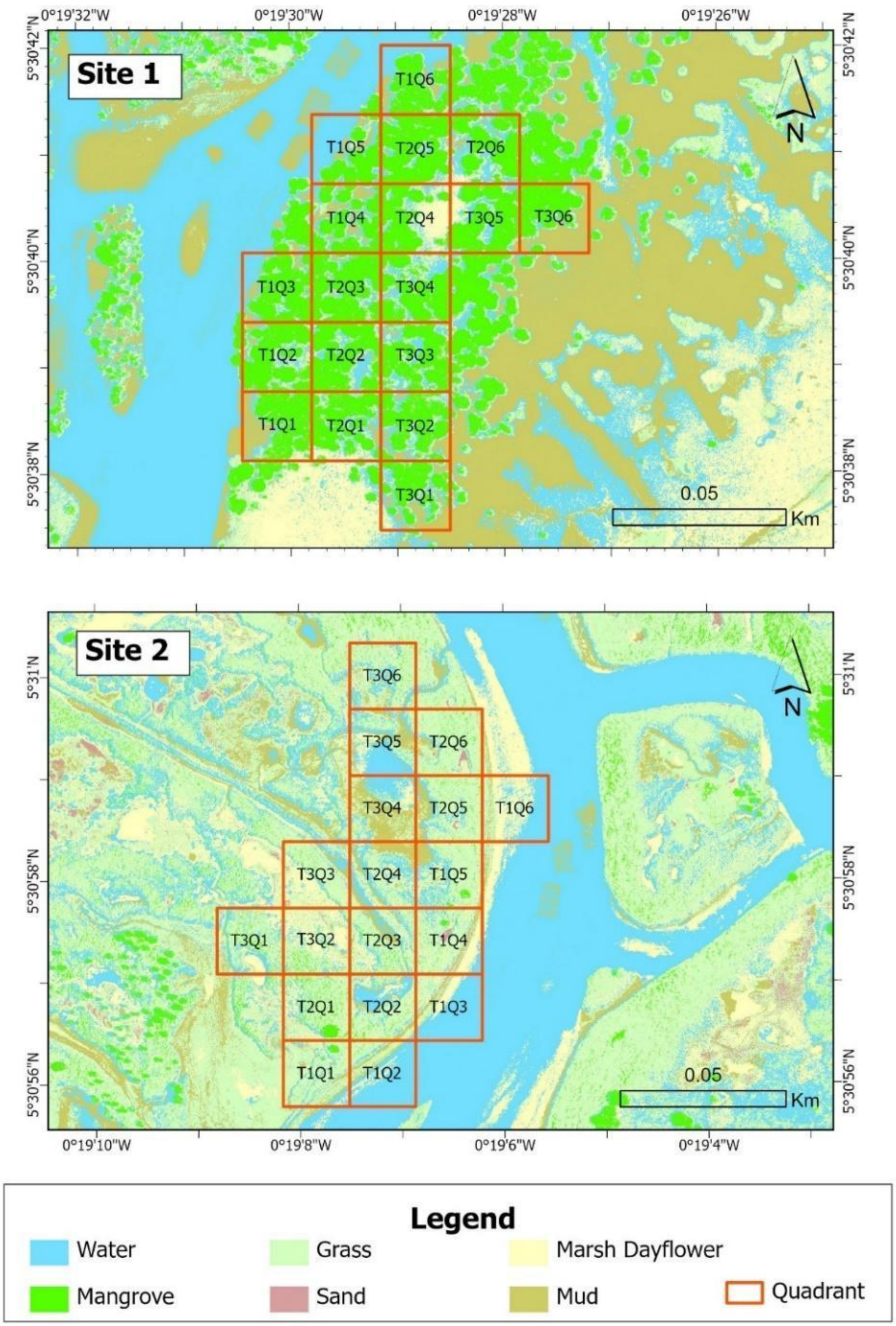

Figure 6: Distribution of land cover types across 18 sampling areas in selected study sites.

Table 1: Extent of different land cover types in sampling areas in Site 1.

Grid ID	Grid area (m^2)	Land Cover (m^2)					
		Water	Mangrove	Grass	Sand	Marsh dayflower	Mud
T1Q1	400.0	37.6	228.6	39.3	1.0	7.2	86.3
T1Q2	400.0	43.2	276.6	56.8	1.7	4.3	17.4
T1Q3	400.0	90.3	247.9	29.7	0.0	2.9	29.2
T1Q4	400.0	70.3	223.6	45.3	0.0	0.0	60.7
T1Q5	400.0	186.7	145.6	27.9	0.0	0.1	39.7
T1Q6	400.0	133.1	190.7	34.4	0.0	0.2	41.5
T2Q1	400.0	54.4	241.1	56.7	0.0	32.8	15.0
T2Q2	400.0	57.9	287.9	44.2	0.0	3.5	6.5
T2Q3	400.0	27.3	320.7	43.1	0.1	2.3	6.4
T2Q4	400.0	37.3	200.4	71.4	0.0	89.6	1.3
T2Q5	400.0	38.5	309.8	42.3	0.0	3.1	6.2
T2Q6	400.0	93.7	216.9	60.5	0.0	13.1	15.9
T3Q1	400.0	77.1	175.1	49.5	0.0	13.6	84.6
T3Q2	400.0	60.8	238.4	54.2	0.0	3.7	42.9
T3Q3	400.0	67.4	255.7	66.4	0.0	2.3	8.2
T3Q4	400.0	64.1	253.9	73.3	0.0	5.6	3.0
T3Q5	400.0	50.0	270.8	41.9	0.0	30.4	6.9
T3Q6	400.0	26.2	190.8	28.7	0.0	0.0	154.3
Total	7,200.0	1216.1	4,274.4	865.7	2.9	214.9	626.0
Average	400.0	67.6	237.5	48.1	0.2	11.9	34.8
Percentage	100.0	16.9	59.4	12.0	0.0	3.0	8.7

Table 2: Extent of different land cover types in sampling areas in Site 2.

Grid ID	Grid Area (m2)	Land Cover (m^2)					
		Water	Mangrove	Grass	Sand	Leafy	Mud
T1Q1	400.0	64.4	11.1	265.0	1.8	24.7	33.1
T1Q2	400.0	263.6	2.3	78.7	0.4	28.3	26.7
T1Q3	400.0	261.9	1.0	67.4	2.8	50.5	16.4
T1Q4	400.0	57.7	11.1	203.6	13.1	97.6	17.0
T1Q5	400.0	74.2	15.3	230.4	1.3	39.7	39.1
T1Q6	400.0	167.0	1.1	56.0	2.2	163.8	10.0
T2Q1	400.0	34.9	48.8	262.3	3.3	47.2	3.5
T2Q2	400.0	112.6	15.3	190.3	1.9	50.6	29.4
T2Q3	400.0	74.8	14.4	210.9	1.7	62.4	35.8
T2Q4	400.0	117.4	4.6	135.5	0.9	54.3	87.4
T2Q5	400.0	50.7	13.1	265.8	2.3	24.7	43.4
T2Q6	400.0	20.1	16.2	315.1	9.1	21.3	18.2
T3Q1	400.0	86.4	21.8	201.3	1.9	73.3	15.3
T3Q2	400.0	42.9	17.1	177.3	4.8	153.0	4.9
T3Q3	400.0	53.1	7.8	195.2	5.1	115.9	22.8
T3Q4	400.0	95.8	1.7	111.5	1.0	35.3	154.7
T3Q5	400.0	178.8	3.1	97.0	1.1	51.9	68.1
T3Q6	400.0	83.9	14.2	234.4	4.3	37.1	26.1
Total	7,200.0	1840.2	219.9	3297.6	58.9	1131.6	651.9
Average	400.0	102.2	12.2	183.2	3.3	62.9	36.2
Percentage	100.0	25.6	3.1	45.8	0.8	15.7	9.1

3.2 Occurrence and Composition of Shellfish Species

The assessment found a total of seven species of shellfish comprising crustaceans, bivalves and gastropods at the Densu Delta sites studied (Figure 7, Table 3). All seven species were encountered at the 2017 replanted Site 1 while only four occurred at the 2023 replanted Site 2. While the West African mangrove oyster and the purple mangrove crabs as well as hermit crabs occurred at Site 1 dominated by mangroves, these species did not occur at the newly planted mangrove area at Site 2 which is dominated by grass. At transect 1 of Site 1(which was the closest transect to the bank of the water) oysters, exclusively occurred on mangrove roots, constituted nearly 50 percent of recorded shellfish for this transect (Figure 8). The absence of oysters at Site 2 could potentially be a result of the lack of well-developed mangrove roots for oyster larvae to settle on.

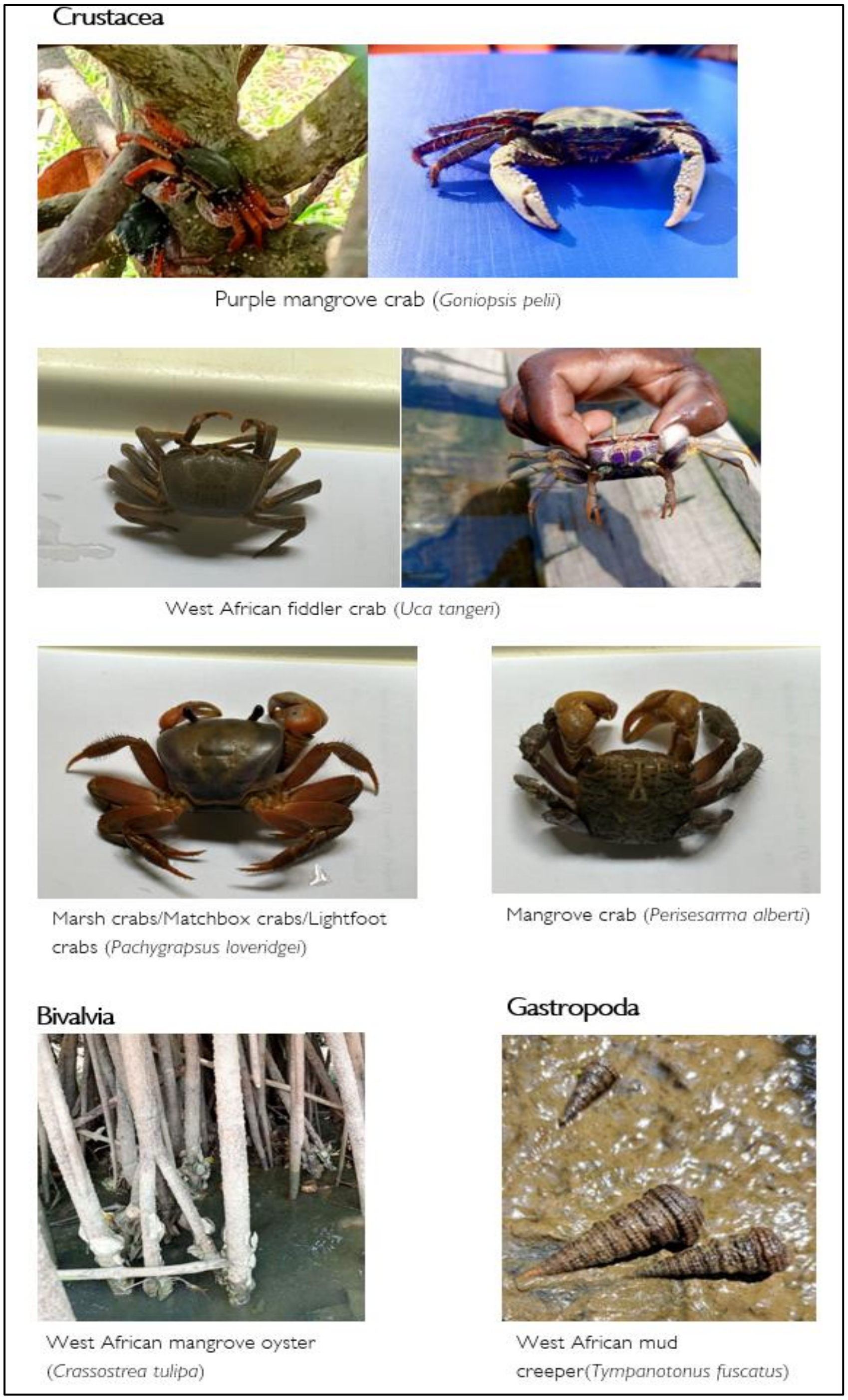

Figure 7: Key shellfish species encountered at the study sites.

Table 3: Occurrence and size range of shellfish species sampled from the two sites at the Densu Delta.

Class	Family	Species	Common name	Occurrence		Size range (cm)	
				Site 1 (2017)	Site 2 (2023)	Site 1 (2017)	Site 2 (2023)
Crustacea	Grapsidae	*Goniopsis pelii*	Purple mangrove crab	+	-	2.6- 4.2	-
	Ocypodidae	*Uca tangeri*	West African fiddler crab	+	+	-	2.0*
	Grapsidae	*Pachygrapsus loveridgei*	Marsh crabs, matchbox crabs, lightfoot crabs	+	+	4.0*	5.0*
	Sesarmidae	*Perisesarma alberti*	Mangrove crab	+	+	3.0 - 3.5	3.0 - 3.5
	Diogenidae	*Clibanarius sp.*	Hermit Crab	+	-	-	-
Gastropoda	Potamididae	*Tympanotonos fuscatus*	West African mud creeper	+	+	3.1-5.5	3.4-4.6
Bivalvia	Ostreidae	*Crassostrea tulipa*	West African mangrove oyster	+	-	-	-
Total number of species				7	4		

* denotes single specimens collected for taxonomic identification purposes

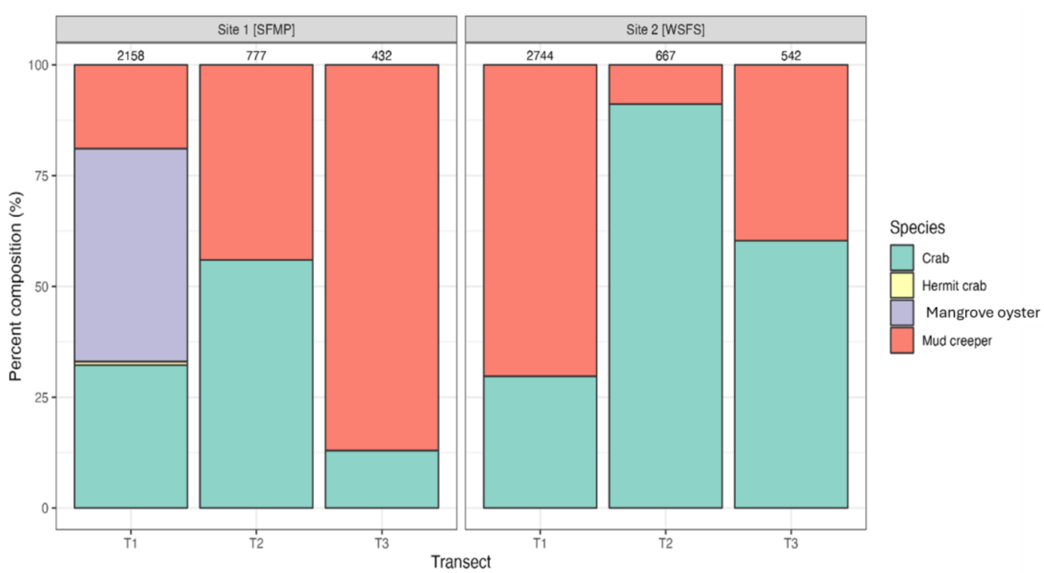

Figure 8: Composition of shellfishes at the study sites (NB: One crab hole represents one crab).

3.3 Density of Shellfish Species

Mangrove oyster had the highest mean density at the Site 1, with approximately 170 oysters per square meter (Figure 9). This was followed by crabs, predominantly the purple mangrove crabs with a mean density of 115 crabs per square meter. As indicated earlier, different crab species were observed in the study, but due to the difficulty in sampling each crab species, the burrows were used as a proxy to estimate the abundance of crabs. The newly planted Site 2 was dominated by the West African mud creeper, commonly mistakenly referred to as "periwinkles" although this is not a true periwinkle..

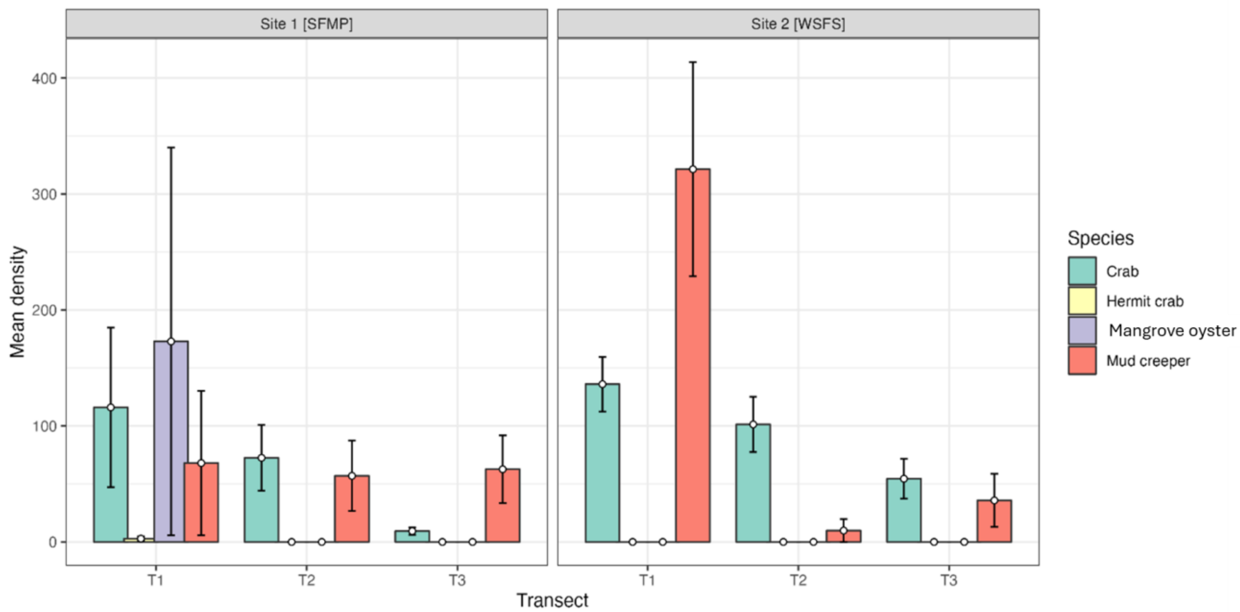

Figure 9: Density per square meter of shellfish species at the study sites

3.4 Diversity of Shellfish Fauna

Overall, Site 1 had higher species diversity and richness, about twice as high as Site 2 (Table 4), with the highest diversity occurring along the water bank (Transect 1) at each of the Site 1 sampled locations. The results show that the shellfish diversity decreases away from the water bank, possibly suggesting that the mangroves along the banks provide habitat for more diverse shellfish species. This trend was not obvious at the newly replanted Site 2.

3.5 Similarity

The degree of similarity between the two sites was estimated to be 0.57, indicating that close to 60 percent of the species were found at both sites. About 40 percent of the species occurring at Site 1, do not occur at Site 2, reinforcing the role of the more developed mangroves planted in 2017 in supporting a more diverse shellfish community.

Table 4: Estimates of species diversity and similarity indices for the two study sites.

	Site -1 (2017)			Site- 2 (2023)		
Transect	Shannon–Weiner diversity index (*H'*)	Species Richness (Margalef Index) (*d*)	Pielou's Species Evenness (*J'*)	Shannon–Weiner diversity index (*H'*)	Species Richness (Margalef Index) (*d*)	Pielou's Species Evenness (*J'*)
1	1.07	0.67	0.78	0.61	0.21	0.38
2	0.69	0.29	0.99	0.29	0.30	0.38
3	0.56	0.69	0.51	0.67	0.32	0.97
Overall	**1.12**	**0.55**	**0.76**	**0.70**	**0.28**	**0.74**
Sorensen's Similarity (Cs) = 0.57						

3.5 Size Distribution of Shellfish Species

As already indicated, due to difficulty in obtaining crab samples, the team collected a few specimens of each species for identification purposes, which were also measured. The team did not collect oysters from the mangrove roots as they were a newly developing population that had to be free from disturbance to allow for population development. Of the crabs collected, the purple mangrove crab (*Goniopsis pelii*) was encountered at only Site 1 and measured from 2.6 cm to- 4.2 cm carapace length. The West African fiddler crab (*Uca tangeri*) measured 2.0 cm carapace length, while the marsh or matchbox crab (*Pachygrapsus loveridgei*) measured 4.0 cm carapace length at Site 1 and 5.0 cm at Site 2. The mangrove crab (*Perisesarma alberti*) was from 3.0 - 3.5 cm at both sites.

The pooled size frequency distributions of mud creeper at Site 1 and Site 2 are illustrated in Figure 10. Mud creepers at Site 1 ranged between 3.11 cm - 5.5 cm, with an average size of 4.19 cm, whereas the range at Site 2 was between 3.41 cm – 4.63 cm, with an average size of 3.78 cm. The mean size of mud creepers at Site 1 is statistically greater than that of Site 2 ($t = 3.24$, $df = 67$, $p < 0.05$). This could be attributed to the improved mangrove vegetation at Site 1, hence, enriching the ecological services of mangroves (Dayal et al., 2022; Lee et al., 2014).

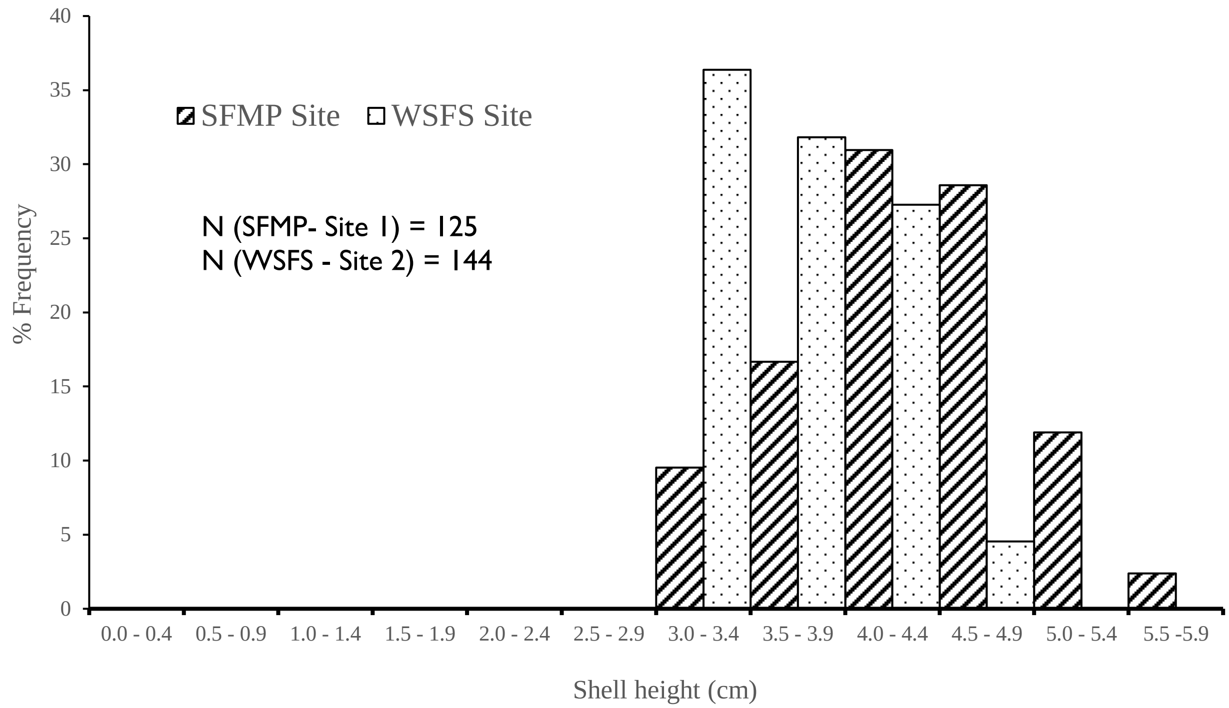

Figure 10 Pooled size frequency distributions of mud creeper (Tympanotonus fuscatus) at the study sites.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Results of the current study show that the SFMP site (Site 1) planted with mangroves in 2017 was predominantly covered by mangroves, and the Women Shellfishers and Food Security project site (Site 2) newly replanted with mangroves in 2023, was predominantly covered by grass. With time, it is expected that mangrove vegetation will dominate in both sites, if reforestation is carried out regularly without mangrove exploitation. The dominance of mangrove vegetation could improve the ecological balance, climate resilience, and shellfisheries production in the Delta. The higher species diversity, higher species richness, occurrence of oysters, and relatively larger mud creepers at Site 1 compared to Site 2, is suspected to be due to the larger mangroves which have developed over seven years after planting, providing habitat for a wider range of shellfish biodiversity. This highlights the benefits of Densu Oyster Pickers Association's (DOPA) mangrove reforestation intervention for enhancing the Densu Delta ecosystem and shellfisheries productivity and provides evidence for the need to support the annual mangrove planting activity planned by DOPA, as indicated in the Densu Delta co-management plan.

4.2 Recommendations

1. More extensive replanting should be supported by the government and donors, as biodiversity benefits are evident in areas that had been reforested with mangroves seven years ago.
2. Continued monitoring should be carried out, including non-reforested control sites and additional time series (less than 7 years and longer than 7 years) to learn more about the pace of ecological and biodiversity changes in reforested sites.
3. In addition, parallel studies on fisheries productivity and livelihood revenues from shellfishing could help to better establish and document the direct linkages between the improved biodiversity and habitats with wellbeing of women shellfishers who depend on shellfishing for their livelihood.

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APPENDICES

Appendix 1: Photographs of some shellfish species sampled

Appendix 2: Raw data of shellfish species sampled

Site 1 (2017)	True Crabs	Periwinkle	Mangrove Oyster	Hermit crab	Total
Transect 1					
Q1	75	379	0	0	
Q2	0	0	0	0	
Q3	14	14	1,008	1	
Q4	437	0	0	11	
Q5	10	11	29	5	
Q6	160	4	0	0	
Total	696	408	1,037	17	2,158
%	32.25	18.91	48.05	0.79	
Transect 2					
Q1	163	0			
Q2	144	0			
Q3	7	14			
Q4	85	160			
Q5	30	144			
Q6	6	24			
Total	435	342	0	0	777
%	55.98	44.02	0.00	0.00	
Transect 3					
Q1	0	0			
Q2	6	23			
Q3	18	0			
Q4	20	54			
Q5	7	170			
Q6	5	129			
Total	56	376	0	0	432
%	12.96	87.04	0.00	0.00	
Overall	1,187	1,126	1,037	17	3,367
% Composition	35.25	33.44	30.80	0.50	

Site 2 (2023)	True Crabs	Periwinkle	Mangrove Oyster	Hermit crab	Total
Transect 1					
Q1	69	171			
Q2	80	219			
Q3	219	336			
Q4	117	119			
Q5	160	336			
Q6	171	747			
Total	816	1,928	0	0	2,744
%	29.74	70.26	0.00	0.00	
Transect 2					
Q1	203	0			
Q2	37	0			
Q3	117	0			
Q4	53	0			
Q5	96	59			
Q6	102	0			
Total	608	59	0	0	667
%	91.15	8.85	0.00	0.00	
Transect 3					
Q1	80	91			
Q2	43	0			
Q3	123	0			
Q4	1	0			
Q5	43	123			
Q6	37	1			
Total	327	215	0	0	542
%	60.33	39.67	0.00	0.00	
Overall	1,751	2,202			3,953
% Composition	44.30	55.70			