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WOMEN SHELLFISHERS AND FOOD SECURITY PROJECT

SITE-BASED ASSESSMENT OF OYSTER SHELLFISHERIES AND ASSOCIATED BIO-PHYSICAL CONDITIONS IN GHANA AND THE GAMBIA

(Milestone #10, Activity 2d)

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Cover photo: Top and bottom left: Project research team conduct research in the Allahein Estuary in The Gambia; bottom right: labelled oyster tissue being packed for morphometric analyses

Photo credit: Rose F. Manga (TRY Oyster Women's Association) and Ernest Obeng Chuku (University of Cape Coast)

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ACRONYMS

CI	Condition Index
CCM	Centre for Coastal Management
CEDAW	Convention for Elimination of Discrimination Against Women
CFU	Colony Forming Units
CPLA	Local Artisanal Fisheries Councils
CRC	Coastal Resources Center
DAA	Development Action Association
DO	Dissolved Oxygen
DOPA	Densu Oyster Pickers Association
DW	Dried Weight
FAO	Food and Agriculture Organization of the United Nations
FC	Fisheries Commission
GI	Gonad Index
NTU	Nephelometric Turbidity Unit
ppt	Parts Per Thousand
SH	Shell Height
SL	Shell Length
SW	Shell Width
WW	Whole Weight
WMW	Wet Meat Weight
SWgt	Weight of the empty shells
UCC	University of Cape Coast
URI	University of Rhode Island
USAID	United States Agency for International Development
WHO	World Health Organization

EXECUTIVE SUMMARY

The Women Shellfishers and Food Security project is a two-year project funded by USAID, co-created and implemented by the University of Rhode Island in partnership with the University of Cape Coast in Ghana, the University of Ghana, TRY Oyster Women's Association in The Gambia, and World Agroforestry. The project draws on successful cases of a rights-based, ecosystem-based, participatory co-management approach to shellfish management by women in mangrove ecosystems in The Gambia and Ghana. The project aims to strengthen the evidence base, increase awareness, and equip stakeholders to adapt and apply successful approaches for replication and scale-up in the eleven coastal West African countries from Senegal to Nigeria.

This is a technical report on the site-based research under Activity 2d of the Women Shellfishers and Food Security Project. Activity 2d involved a one-year study of shellfisheries, shellfish biology, and physicochemical analysis of water within six estuarine and mangrove ecosystem-based livelihoods sites, three each in Ghana and The Gambia. Field data collection commenced in March 2021 and ended in March 2022, while laboratory processes continued to the end of May 2022, and results are presented in this report.

The six sites for this study were selected in a previous site-selection assessment of sixteen and six sites in Ghana and The Gambia, respectively. Based on two main criteria, that is, the existence of women-led shellfisheries at the sites and variations in mangrove health, classified into low, medium, and high health, the Densu, Narkwa, and Whin systems were selected for Ghana and the Allahein, Bulock, and Tanbi systems were selected for The Gambia. Several research activities were conducted at five different stations established at 500 m to 1 km apart (from one station to another) in each of these estuaries. The main research tasks undertaken under Activity 2d at all the six research sites were:

(i) Assessment of water quality (physicochemical properties, nutrients, microbial load, heavy metals),
(ii) Assessment of oyster biology [morphometrics, condition index, sex ratio],
(iii) Assessment of oyster fishery, governance and socioeconomics, identify existing status of the shellfisheries, and number of shellfishers, and,
(iv) Ranking of sites into high, medium, and low levels of exploitation, pressure, and fishery health.

Monthly data collection on physico-chemical properties of the estuaries (depth, temperature, salinity, dissolved oxygen, pH, and turbidity) were conducted at all six sites. Quarterly data collection on nutrients (phosphates and nitrates), microbial loads (total coliform, fecal coliform, and *E. coli*), and heavy metals (Pb, Hg, As, Cr, and Cd) in both water and oyster flesh, were executed at all sites. Biometric data (shell heights, shell lengths, whole weight, shell weight, meat weight, and dry weight) on oyster samples was collected every month for all six sites. Sex determination by visual observation and histological processes was conducted on oyster specimens from all six sites. In addition to these biological and ecological studies, two separate social surveys, one on the socioeconomics of shellfishing households and another on oyster fishery were conducted in the adjoining communities of the six sites. Further studies on the oyster exploitation were also conducted by collecting the catch and effort data at each site.

The results show overall dynamic scenarios at the various sites for all parameters considered in this study. Key results are summarized in the bullet points below.

Hydrographic conditions of the systems studied:

- The Gambia systems were observed to be relatively deeper than those of Ghana, Tanbi being the deepest and Whin the shallowest.
- Higher temperatures were recorded in the Ghana systems and lower temperatures in The Gambia systems from December to March 2021. The reverse was observed from June to October, and then switched again in November 2021 to March 2022.
- More stable salinities were recorded, between 20 ppt and 42 ppt, throughout the study period in The Gambia. Wide fluctuations were recorded in Ghana's waters, dropping as low as almost 0 ppt in all the Ghana systems in June during the peak of the rainy season.
- Dissolved oxygen concentrations in the systems studied ranged from an average of about 3 mg/l to 10 mg/l. There were observable hikes in the months of April and May 2021 for The Gambia ecosystems and in December for the Whin estuary and Narkwa lagoon in Ghana.
- Turbidity was low in The Gambia systems and much higher in Ghana systems, generally highest in Whin.

Nutrients, heavy metals, and microbial levels:

- Nutrients (phosphates and nitrates) exceeded the optimum limits, but nitrate, which is the limiting nutrient in seawater, did not significantly exceed levels beyond 5 mg/l to drive algal bloom in the systems.

- Coliforms, fecal coliforms, and Escherichia coli occurred in both water and oyster tissue at all sites. Comparatively, higher total coliform count was recorded in the waters at the sites in Ghana than The Gambia. The total coliform and fecal coliform (including *E. coli*) were largely within the approved standards, except at the peak of the rains in June 2021 at the sites in Ghana, and September 2021 in the Tanbi.

- The levels of Mercury, Arsenic and Chromium were largely within WHO permissible limits in the oyster tissue although some occurred above permissible limits in the water bodies, while Lead and Cadmium were generally above the acceptable limits in the oysters.

Oyster biology and exploitation:

- The largest sizes of oysters were found in Bulock and the smallest in Narkwa. Oysters in The Gambia systems were generally larger in March-May while in Ghana, larger sizes occurred in Sept-October. The modal sizes in The Gambia were about 6 cm while modal sizes in Ghana were about 4 cm (except in the Densu Delta where it is 6 cm).

- Condition Index was generally higher in March for The Gambia, and in August-October for Ghana, which coincided with periods when the shellfisheries were open for harvesting at the managed sites, and this enables shellfishers to optimize the harvests of oysters in good condition.
- The oysters from Bulock had the largest maturity size (5.6 cm), followed by Densu (5.4 cm), Allahein (5.3cm), Tanbi (5.2 cm), Whin (4.9 cm), and the smallest in Narkwa (3.6 cm).
- Densu and Tanbi oyster stocks are under exploited, Whin and Allahein are optimally exploited while Narkwa and Bulock stocks are overexploited.

Socioeconomics, oyster fishery, and governance:

- A general trend of better living conditions and an empowered women community of oyster harvesters were identified for the Tanbi in The Gambia among all the communities studied. The women shellfish harvesters of Tanbi are comparatively well-off considering the poverty indicator, wealth measured by household structure, and household income.
- Whin and Narkwa sites in Ghana have no existing structures for governing the oyster fishery. However, the other four sites have varied levels of governance structures and management mechanisms for the fishery, ranging from largely shellfisher and community-led management regimes (Allahein and Bulock) to formalized co-management regimes with exclusive use rights granted to the shellfishers by the government (for Tanbi and Densu).
- With regards to the involvement of shellfishers in decision making, the sites with governance structures and management regimes strongly integrate the women shellfishers in decision making processes.

Recommendations are for steps towards initiation of women-led co-management modalities at the sites without management modalities for the fishery in order to sustainably manage the overexploited stocks.

1. INTRODUCTION

1.1 Project Summary

In August 2020, USAID awarded the University of Rhode Island (URI) the Women Shellfishers and Food Security project. With USAID, URI co-created the project in partnership with the University of Cape Coast (UCC) in Ghana, the University of Ghana, TRY Oyster Women's Association in The Gambia, and World Agroforestry. The Women Shellfishers and Food Security project will strengthen the evidence base, increase awareness, and equip stakeholders to adapt and apply successful approaches for replication and scale-up in the eleven coastal West African countries from Senegal to Nigeria. It will draw on successful cases of a rights-based, ecosystem-based, participatory co-management approach to shellfish management by women in mangrove ecosystems in The Gambia and Ghana developed with USAID assistance. Knowledge and experience generated through the project will facilitate opportunities for improvement and broader application of these promising approaches in West Africa through these key project activities:

1) Conduct the first-ever participatory regional assessment of the situation, needs, and promising approaches to shellfish co-management led by women across the eleven countries and the scope of the potential sectoral and cross-sectoral benefits.

2) Elaborate and test elements of models based on existing approaches through site-based research in The Gambia and Ghana to strengthen the evidence base for successful elements of the model.

3) Foster a community of practice around the development and dissemination of a toolkit on a rights-based, ecosystem-based, participatory co-management of shellfish by women in mangrove ecosystems in West Africa with and for community, national, and regional level stakeholders.

1.2 Purpose of this Report

This report presents an overview of UCC activities for the site-based research on shellfisheries, shellfish biology, and physicochemical analysis of water within six estuarine and mangrove ecosystem-based livelihoods sites. UCC conducted participatory shellfish stock assessments looking at stock sizes, maturity levels (size at maturity), and determined trends of exploitation. Water quality parameters were sampled, including physicochemical parameters, heavy metal content (mercury) and microbial levels (i.e., total and fecal coliforms including *E. coli*). These data were used to determine the status of the fishery and ecosystem health at the six sites. Participatory assessments documented governance and other socioeconomic variables used in the cross-sectoral multivariate analysis.

1.3 Background and Context

The West African mangrove oyster (*Crassostrea tulipa*) fishery as a complex socio-ecological system, is characterized by a triangulated strong dependence of resource users (mainly women) on the biological populations and stocks of oysters, which also depend strongly on the biophysical environment with its inherent physical, chemical, and ecological characteristics (Figure 1).

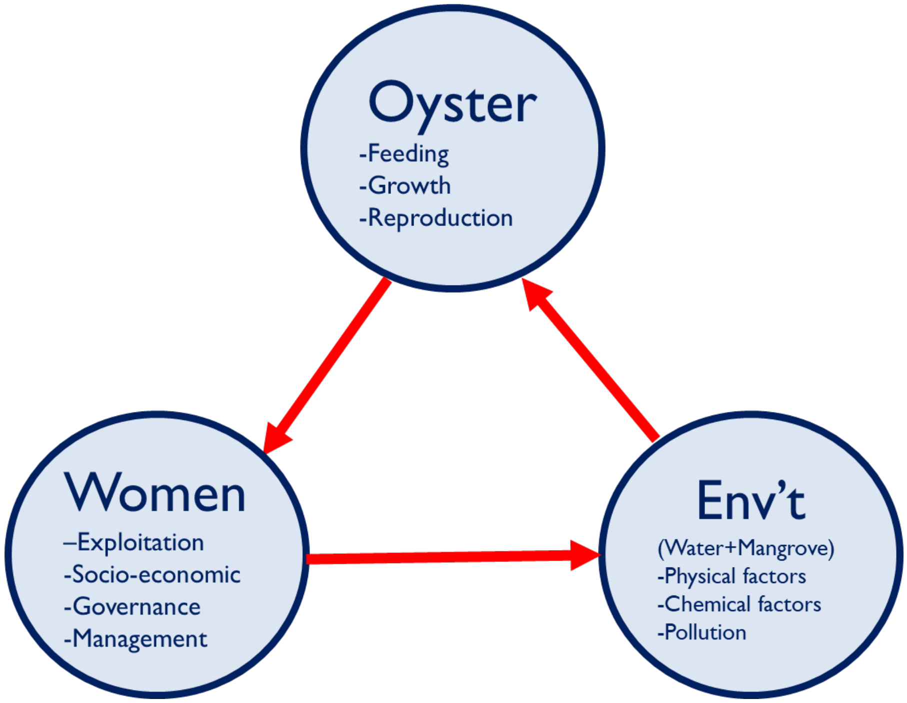


Figure 1: The triangulated relationship of key parameters considered in the assessment.

To cover these components of the fishery for comprehensive understanding of the nexus between the social systems and ecological outputs, the assessment covered water quality parameters, mainly physico-chemical conditions, nutrient levels and selected potential pollutants to oyster food safety (coliforms and heavy metals), the biology of the oyster population (growth, maturity, reproduction), the fishery (exploitation and sustainability), the social systems (governance structures and management regimes), and economic and livelihood regimes (incomes, alternative livelihoods, etc.). These parameters were assessed at the six selected sites in Ghana and The Gambia for comparison across sites.

Figure 2: A UCC Research team member with oysters on mangrove roots in the background at Bulock estuary in The Gambia.

1.3.1 Water Quality

1.3.1.1 Biophysical environment

Physico-chemical conditions

The survival of bivalves in the wild is influenced by environmental factors (Villarroel et al., 2004). Studies have shown that varying hydrographic condition have a significant effect on *Crassostrea tulipa* and other bivalves' growth and reproduction (Obodai et al., 1996; Buitrago et al., 2009; Efiuvwevwere and Amadi, 2015; Chuku et al., 2020; Osei et al., 2021). The oysters of the genus *Crassostrea*, in general, are considered organisms capable of resisting the variability of environmental factors and are considered euryhaline organisms (Quayle, 1989). It is therefore imperative that these hydrographic factors are closely monitored to assess how they affect oyster growth and reproduction in general. Physico-chemical parameters studied were depth, water temperature (°C), dissolved oxygen (mg/l), turbidity (NTU), salinity (ppt), and pH.

Temperature controls many physiological processes in oysters including feeding (Gosling 2015), although elevated temperatures within the tolerable range (15° C to 36° C for most tropical oysters) can still support the growth of larval and adult oysters, provided food is available; (Angell, 1986; Arakawa, 1990). *Crassostrea tulipa* is reported to tolerate thrive in temperature range of 8–33° C (Chuku et al., 2020; Osei et al., 2021; Mahu et al., 2022). Salinity is one of the most important conditions that support oyster growth and other physiological activities. The species are euryhaline and can survive a wide range of salinity differences (Asare et al., 2019), however, very low levels can be detrimental to the growth and survival of oysters due to reduced or no feeding and physiological stress (Osei et al., 2021). *Crassostrea tulipa* reportedly thrives in salinities between 4 parts per thousand (ppt) and 50 ppt (Chuku et al., 2020; Osei et al., 2021; Mahu et al., 2022). Salinities below and above this range are potentially detrimental to growth and survival of the species. Prolonged exposure to a salinity of 0 ppt causes mortalities. In addition, low levels of dissolved oxygen and pH may be lethal to or inhibit survival of the organisms (Bhatnagar et al., 2004). A pH range of 6–9 is reported for *C. tulipa*, and extremely low and high pH has significant detrimental effects on shell development (Chuku et al., 2020; Osei et al., 2021; Mahu et al., 2022). *C. tulipa* is reported to thrive in varied dissolved oxygen (DO) concentrations in different systems, surviving in estuarine conditions from 10 mg/L to as low as 1 mg/L (Chuku et al., 2020; Osei et al., 2021; Mahu et al., 2022). Turbidity also affects the activities of oysters as it is a measure of the amount of suspended matter or silt in the water column. *C. tulipa* reportedly thrives in turbidities up to 60 NTU (Chuku et al., 2020; Osei et al., 2021; Mahu et al., 2022). High amounts of suspended silt negatively impact their survival. Blay (1990) reports that the presence of a significant amount of silt might trigger bivalves to close their shells and this can prevent feeding resulting in slower growth and higher mortalities. This is due to the fact that bivalves are filter feeders and their gills may get clogged when there is increased turbidity. Assessing these varying physico-chemical factors can help explain observations in the physiological activities such as growth and reproduction of oyster populations.

Nutrients

Nutrients are essential for growth and development of all living organisms. They are a prerequisite along with light for photosynthetic processes (Roleda & Hurd, 2019). Naturally, nutrient additions to estuarine systems and other coastal water bodies occur through geological activating such as weathering of nutrient-rich rocks, river inflow and regeneration (Nie et al., 2018). However, human population growth in recent decades and associated activities that contribute other nutrient-sources, including activities of mining, agriculture, fossil fuel consumption (atmospheric deposition), wastewater treatment plants, among others have increased nutrient concentrations in coastal ecosystems (Horta et al., 2021). The optimum limits of 0.1 mg/l phosphate and 1.0 mg/l nitrate are recommended as the suitable levels in estuaries and other coastal ecosystems that prevents algal blooms (NOAA/EPA, 1988). Consequently, these elevated nutrient inputs, particularly nitrate and phosphate have direct linkage with algal bloom and eutrophication, which is considered one of the greatest threats to the ecological health of coastal ecosystems (Malone & Newton, 2020). Nevertheless, nutrients are regarded as one of the major drivers of phytoplankton productivity (Human et al., 2018). But the uptake and cycling of macronutrients introduced into estuarine ecosystems by phytoplankton depend on other physicochemical variables and a range of interlinked hydro-geomorphological processes (Kuuppo et al., 2006). Low or high nutrient availability for algae production may have direct consequences for estuarine organisms, including oysters which are filter feeders that depend on algae for their nutritional requirement, growth, and performance of other biological processes including reproduction.

1.3.1.2 Potential contaminants and oyster food safety

Microbial and coliform concentrations

Water has been reported to be prone to a wide range of microbial and other potential contaminants. Poor microbial quality of water has a high potential of harming the aquatic ecosystem as well as the health of the consumers of food sources from these ecosystems (Dunn et al., 2014; Onyango et al., 2018). The disease-causing microorganisms are usually contracted by fecal-oral means, which then pose a great public health danger to the consumer. Organisms such as *Escherichia coli*, fecal coliforms, fecal streptococci and *Pseudomonas aeruginosa* are usually considered as indicator organisms and their presence in water poses a detrimental health threat. Indicator organisms are considered to be microorganisms such as bacteria and viruses in water bodies and are often used as surrogates to examine the presence of pathogens in an environment (NRC, 1985; Motlagh & Yang, 2019).

Fecal coliform bacteria are indicator organisms which are found in the intestines and feces of humans and other warm-blooded animals. Fecal matter from humans have been regarded to be responsible for increased risk of waterborne infection and diseases. Most Total Coliforms are regarded less harmful in general, while a representable population are considered pathogenic (Proshad et al., 2017). Fecal matter contamination from intestinal microorganisms have been recognized to be the primary cause of natural water resource contamination. This leads to Infections such as diarrhea and typhoid fever which have been reported endemic among children in developing countries (Abhirosh et al., 2011).

Shellfish contamination has been increasing due to increasing water contamination, largely caused by waste contamination by animal and human fecal matter, effluents from sewage, and runoff from rainwater. This contamination occurs when the waterbody is in close proximity to urbanized areas. Shellfish are filter-feeders. They accumulate microorganisms from their environment and concentrate the microbes to elevated numbers. When oysters are consumed, they are capable of transferring these microorganisms into the consumer food chain, leading to food-borne diseases (Miotto et al., 2019). This study therefore assessed the coliform and *E. coli* levels across the six sites in order to understand health risks regarding shellfish consumption.

Heavy metals

Seafood and fish are excellent sources of the cardio protective fatty acids docosahexaenoic (DHA) and eicosapentaenoic (EPA). As a result, many public health authorities recommend eating at least 1–2 servings of fish per week to prevent diet-related chronic diseases (WHO, 2003). Unfortunately, anthropogenic activities such as mining, agriculture, and industrial waste releases significantly increases naturally occurring heavy metal levels in the environment, including the marine ecosystem (Agah et al., 2009). As a result, marine organisms including shellfish, fish, and crustaceans accumulate these metals to potentially toxic levels. Often, these organisms are the main sources of human exposure to metals in the general population (Malik et al., 2010; Saha & Zaman, 2013).

Foods containing toxic metals above permissible levels are considered harmful to human health and are prohibited from trade under many national and international regulations. The toxic effects of these metals include teratogenic effects (Hg), decreased cognitive function (Pb, Hg), impaired reproductive capacity (Cd, Pb), impaired renal (Pb, Cd, Hg) and liver (Pb and Cd) function, hypertension (Cd), neurological changes (Hg, Pb), and cancers (Cd) (Lee et al., 2011; Mattia et al., 2004). Heavy metals are deposited in sediment and water from industrial and other sources and seriously affect the environment and aquatic organisms. Aquatic animals accumulate large quantities of xenobiotics, and the accumulation depends on the intake and the elimination from the body (Karadede et al., 2004). Of the different aquatic organisms, clams, oysters, and mussels accumulate large quantities of heavy metals. Oysters are often used as indicators of marsh and estuarine health (Sajwan et al., 2008). Because oysters are suspension feeders that filter water, they retain small particles within their body (Day et al., 1989; Djedjibegovic et al., 2020). Therefore, they are ideal pollution indicators and are frequently used in environmental assessment and monitoring (Haye et al., 2006). However, there have been few detailed studies of heavy metal contamination in terms of the spatial variation of heavy metal levels in water and oyster tissue (e.g., Catry et al., 2021; Solitoke et al., 2021). This research studied the heavy metal contamination in surface water and oyster tissues from different sampling sites in Ghana and The Gambia and compared the levels to permissible limits. The heavy metals assessed were Cadmium (Cd), Arsenic (As), Mercury (Hg), Lead (Pb) and Chromium (Cr) in the water and the oyster meat, and concentrations were compared to World Health Organization (WHO) permissible standards.

1.3.2 The Oyster Population

1.3.2.1. Growth and condition

Sizes and growth

Like all other organisms, the growth and well-being of oysters are strongly tied to the favorability of their environment. Shell morphometrics provide useful metrics for assessing size variations, relationships, and growth for comparison among different populations and potential effects of varying exploitation levels. These include shell height (SH) which measures the maximum distance from the hinge/umbo to the ventral shell margin, the shell length (SL) which measures the widest distance perpendicular to the shell height, and them shell width (SW) which measures the thickest part of the two shell valves, the whole weight (WW), wet meat weight (WMW), weight of the empty shells (SWgt) and the dried weights (DW) of oysters.

Condition

The Condition Index (CI) of bivalves is used to describe the degree of fatness or the extent to which the meat fills the shell (Quayle, 1980), and it is of significant importance in the fishery. It indicates the commercial quality of the species (Davenport & Chen, 1987) and it is expedient to monitor the index of oysters as it helps harvesters determine the most suitable time(s) of the year for harvesting (Yankson, 2004). Seasonal changes in CI result from complex interactions of a variety of factors, including food, temperature, salinity, and the metabolic activities of bivalves, particularly the growth and reproductive processes (Hickman & Illingworth, 1980; Thippeswamy & Joseph, 1988).

1.3.2.2 Reproductive biology

Gonadal development, maturity, and sex ratio

Knowledge of the reproductive cycle of oysters is important for fisheries management (da Costa et al., 2012). This information is useful in predicting the suitable period and condition for controlling the harvesting of the species to allow for breeding and population replenishment. Sexual identification can be done through visual observation of gonad smears under the microscope or histological preparations of the gonads. However, the most reliable methods for studying the reproductive cycle in bivalves are those based on either histological or squash preparations of the gonads (Gosling, 2003), where observations are made under regular periods throughout the year to identify the progressive development of oocytes and the subsequent changes in morphology of the gonad tissue over time (Seed, 1976; Seed & Suchanek, 1992).

The study investigated the quarterly reproductive state of oyster fisheries at Densu Delta, Narkwa Lagoon, and Whin Estuary in Ghana, and Allahein, Tanbi, and Bulock estuaries in The Gambia. The gonadal development of the oyster populations, sex ratio, and maturity size were assessed.

1.3.3 The Oyster Fishery

1.3.3.1 Exploitation and sustainability

One of the key components of fisheries management is stock assessment which is carried out to ascertain the levels of exploitation of stocks, define their present stock size, and also to predict future yields (King, 2007). Assessment of growth and mortality characteristics, exploitation, and maximum sustainable yield of oyster stocks provide very useful biological reference points for setting management objectives and sustainable management of the stocks. These parameters require data from mainly effort, catch, and sizes (length and weight) of the organisms. Management measures that emanate from these analyses focus on ensuring optimum yield while promoting biological and economic sustainability.

1.3.3.2 Socio-economics and governance

Socio-economic situation of Shellfishers

Oyster fisheries contribute to the livelihoods of women engaged in the fishery, and also to a variety of social and economic services in their households and in society at large (Gopal et al., 2012). However, in Africa, there are some differences between men and women in education, health, employment, income prospects, asset control, personal security, and political engagement (Biswas, 2002), and they play very direct and indirect active roles in the fisheries sector. For instance, women make up half of the workers in inland fisheries in West Africa, selling about 80 percent of all seafood in the region (GIZ, 2013). Even though women work throughout the fisheries value chain, post-harvest activities such as processing and trade account for the majority of their work in the regular artisanal fisheries (AUC & NEPAD, 2014). In the oyster and some other coastal shellfisheries however, women harvesters dominate all nodes of the value chain (Chuku et al., 2021; Chuku et al., 2022), emphasizing the importance of these fisheries to the socio-economic well-being of women living in coastal areas of West Africa.

Low income among women in fisheries, and the inability of these women to access loans from financial institutions, especially banks, is still very significant, but women possibly have higher potential for participation in informal savings schemes than men (Ikeogu et al., 2020).

These factors, together with others such as low levels of education and lack of tenure rights have very strong bearing on the socio-economic circumstances of women in shellfisheries, and the current study explored these factors among the women shellfishers at the study sites. This is important as the social and economic circumstances of shellfishers could be drivers of overexploitation on one hand, or a conduit for sustainable exploitation.

Governance structures and management modalities

Governance structures and modalities for managing fisheries resources are very important for sustainable exploitation of the resource. Despite the significant contribution women make in the fisheries sector in Africa, the role of women in fisheries in general is undervalued and their contribution to fisheries governance is limited (Du Preez, 2018; UN Women, 2020). Generally, across the sub region, most of the activities of women in the fisheries sector are sometimes seen as an extension of their domestic roles and are therefore not considered in policy and management planning. Women are therefore most affected by issues such as natural disasters, climate change, overfishing, and loss of biodiversity as they are generally not accounted for fully in governance and management decisions (Lentisco & Lee, 2015). Over the years however, this situation has seen some level of improvement with increased discussions on various platforms on the importance of the participation of women in fisheries governance. International agreements such as the Convention for Elimination of Discrimination Against Women (CEDAW) in 1979 set the standards and principles for ensuring women's rights are considered in all sectors (UN Women, 1979). The World Conference on Women in 1995 also adopted the Beijing Declaration reinforcing global commitment to equity, development, and peace for women across the world (Fourth World Conference on Women, 1995). These agreements have provided the basis for socio-economic development and empowerment of women in economic sectors including fisheries.

Within the fisheries sector, beyond these international agreements, specific fisheries management projects have focused attention on empowering women and improving the visibility of the role of women in fisheries. In West Africa, through projects such as the USAID Sustainable Fisheries Management Project implemented in Ghana, the USAID COMFISH Project in Senegal, the Sustainable Fisheries Livelihood Programme in Africa implemented by the Food and Agriculture Organization of the United Nations (FAO), and the West Africa Regional Fisheries Programme, among others, the roles of women have been integrated in many studies, policies, workshops, and other country-specific programs (Coastal Resources Center, 2016; EJF, n.d.; Lentisco & Lee, 2015; USAID FtF and Biodiversity COMFISH Plus Project, 2018). The FAO's Voluntary Guidelines for securing small-scale fisheries emphasizes the role of women and the need to ensure equitable participation of women in the design and planning of fisheries management measures as well as the need to ensure that the distribution of fisheries resources is equitable and takes into consideration women and other vulnerable groups (FAO, 2015).

The attention received over the past few years has increased women's access to fisheries resources, tenure rights, processing technologies, training, loans, and grants to finance their activities. It has also led to a greater recognition of women in fisheries policy making and management planning. Within the broader artisanal fishery in West Africa, some progress of women's involvement in fisheries governance can be highlighted. In The Gambia for example, through the National Fisheries Post-Harvest Operators Platform, women have participated in the formulation of the local Fisheries Act (Lentisco & Lee, 2015). In Senegal, the Local Artisanal Fisheries Councils, known as CLPAs – Conseils Locaux de Pêche Artisanale - which are the legally recognized district-level governance structure for artisanal fisheries, now have women represented as part of leadership and they have contributed to the development of specific fisheries management plans. Beyond this, Senegalese women in the fisheries sector have formed a civil society organization called the Network of Women in Artisanal Fisheries in Senegal (also known by its acronym in French as – REFEPAS – Réseau des femmes de la pêche artisanale du Sénégal) which has resulted in their representation and contribution to conferences, policy dialogues, and workshops where they were previously unrepresented (Coastal

Resources Center, 2016). In Ghana, the West Africa Regional Fisheries Programme in 2015 facilitated establishment of the National Fish Processors and Traders Association which has improved the representation of women in the fisheries sector (Owusu, 2020; Torell et al., 2015). These provide good examples of facilitating women's voice, space, and recognition in governance in the artisanal fisheries sector in West Africa.

Exploring the governance structures and modalities in the West African coastal shellfisheries is of particular interest because the fishery is dominated by women harvesters at all nodes of the value chain (Chuku et al., 2021; Chuku et. al., 2022). Given that the governance of fisheries resources is key in driving the sustainability of its exploitation and utilization, results of water quality, oyster growth, and exploitation could have significant bearing on governance regimes and management modalities at each of the six sites under study in Ghana and The Gambia. Already, the leadership of women shellfishers in the governance of shellfisheries at two of the sites, the Tanbi wetlands in The Gambia and the Densu Delta in Ghana is reported and well known across the Sub-region. The government of The Gambia set a precedent in Sub-Saharan Africa by giving the Try Oyster Women's Association exclusive use rights and authority to sustainably manage the oyster and cockle fishery in the Tanbi Wetland National Park (Gambia Ministry of Fisheries Water Resources and National Assembly Matters, 2012; Coastal Resources Center, 2016). Similarly in Ghana, the government has given the Densu Oyster Picker's Association exclusive use rights and authority to sustainably manage the oyster fisheries in the Densu Delta (Ghana Ministry of Fisheries and Aquaculture Development and Fisheries Commission, 2020). To allow for effective comparison of the state of the oyster fisheries with existing management regimes across the six sites, this study assessed the existing governance and management systems.

2. METHODOLOGY: THE STUDY SITES, SAMPLING, DATA COLLECTION AND ANALYSES

2.1 Study Sites in Ghana and The Gambia

The sites for this study were selected in an earlier project activity through field assessments of various communities and water bodies in both Ghana and The Gambia. These are presented in the Site Selection Report of this activity (see CRC, 2020). Three sites were selected in each country for in-depth studies on water quality, oyster biology, fishery, and socioeconomics. For Ghana, Densu Delta, Narkwa Lagoon, and Whin Estuary were selected. In The Gambia, the Allahein, Tanbi, and Bulock estuaries were selected. The purposive selection of sites was based on several metrics including the presence of a women's oyster fishery (shellfishing livelihood) and the existence of mangrove vegetation. The level of mangrove health was qualitatively assessed for the six water bodies into three categories: low, medium, and high conditions of health (Table 1).

Table 1: Qualitative health (in terms of mangrove degradation) at the six selected sites in Ghana and The Gambia.

Country	Health of ecosystem by mangrove degradation		
	Low	Moderate	High
Ghana	Densu Delta	Narkwa Lagoon	Whin Estuary
The Gambia	Allahein	Tanbi	Bulock

* *Low health has the most degradation and high health has least mangrove degradation.*

Detailed information about the sites is available in the report on site selection (see CRC, 2020). For each water body selected, five stations were established for sampling of water parameters and collection of oyster samples for analysis. These five sites were marked across the breadth of each water body covering the mouth to the head region of the system where possible. In very large systems such as the water bodies in The Gambia, subsequent stations were established at least 500m apart.

2.1.1 Densu Estuary (Ghana)

The greater Densu Delta (Figure 3A) is a RAMSAR site designated in August 1992 and located west of Accra in the Greater Accra Region of Ghana. The Delta covers an area close to 6,000 ha. The wetland receives water mainly from the Densu River, which supplies water to approximately half of the Accra metropolitan area. The Weija Dam controls freshwater flow from the Densu River and the Weija Reservoir into the Delta. The immediate surrounding communities are predominantly fishing communities. Its location is in a cosmopolitan area with fast urbanization leading to encroachment in the northern parts of the wetland. Inhabitants of Bortianor, Tsokomey, Tetegu, and Faana communities use the water areas of the Delta for navigation and tourism purposes. Oyster harvesting is a major livelihood for the women, supported by their children. There are about 150 women and 10 men oyster harvesters/divers. The oyster fishery is currently regulated by a community-based management plan approved by the Fisheries Commission of the Ministry of Fisheries and Aquaculture Development of Ghana, developed with the assistance from the Development Action Association (DAA), a community Non-Governmental Organization (Ghana Ministry of Fisheries and Aquaculture Development and Fisheries Commission, 2020).

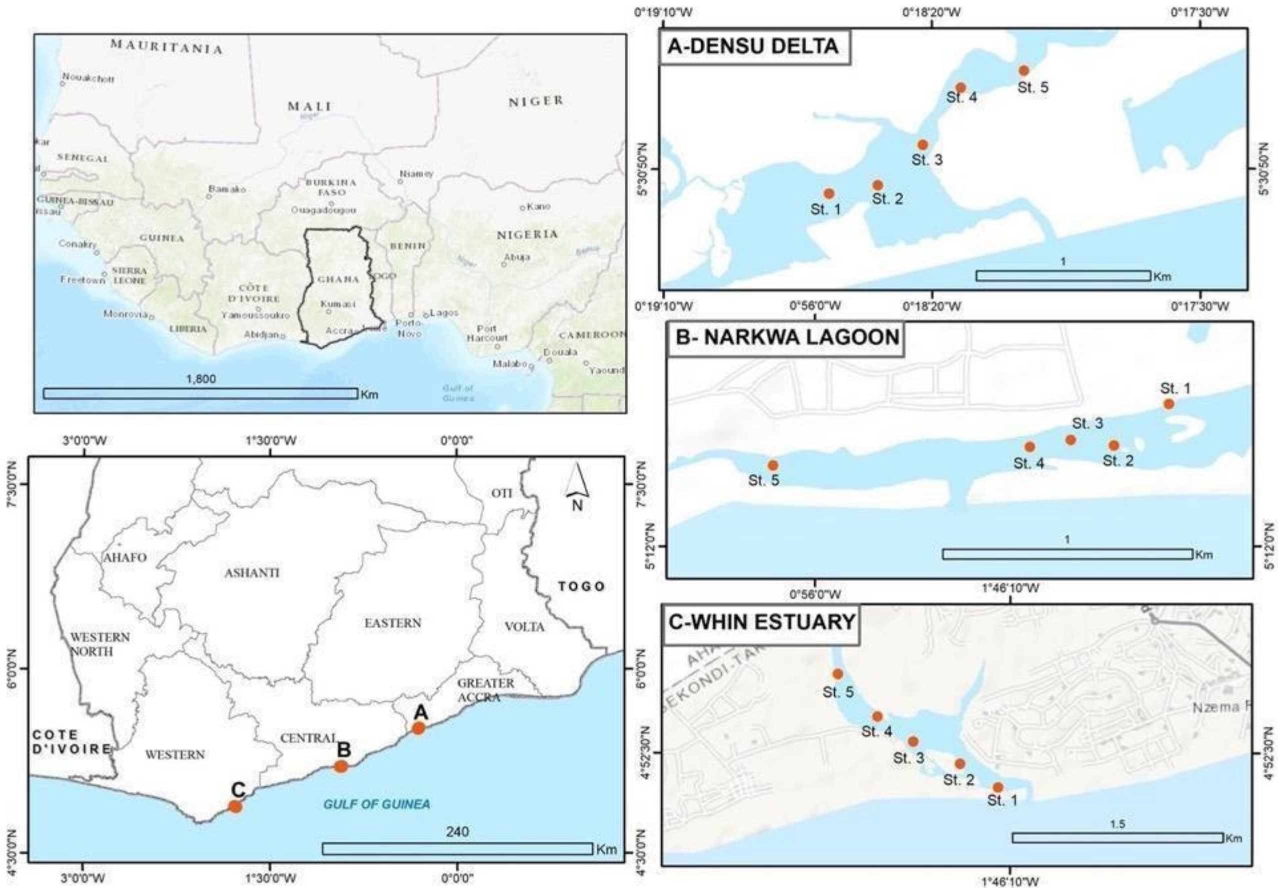


Figure 3: Map of Ghana showing the selected sites and sampling locations at each site.

2.1.2 Narkwa Lagoon (Ghana)

The Narkwa Lagoon (Figure 3B) is located south of the Ekumfi Narkwa community in the Ekumfi District of the Central Region of Ghana. Narkwa lagoon is formed by the flow of one of the two main tributaries of the Okye River which discharges into the sea through the lagoon. Conservatively, the lagoon covers about 110 ha of estuarine and littoral vegetation (mainly mangroves) in the north-eastern section of the lagoon. Important food fish of the lagoon include finfish such as black chin tilapia (*Sarotherodon melanotheron)* and shellfish such as the bloody cockle (*Anadara senilis)* and mangrove oyster (*Crassostrea tulipa).* The finfish are mostly harvested by men whereas women dominate the shellfish harvesting. Women account for about 89 percent of shellfishers in a survey conducted in 2016 (Asare et al., 2019) whereas the cockle harvesting involves some substantial participation by men. There is a section of the Narkwa community, the south-eastern area, where the people's livelihood is primarily based on oyster trade, harvesting, processing, and marketing. These species are harvested from the bottom of the lagoon; oysters from sandy-mud areas and cockles from more muddy areas.

2.1.3 Whin Estuary (Ghana)

The Whin Estuary (Figure 3C) orients itself oblique to the sea, relative to the shoreline at its narrow mouth. It is a shallow system with a few deep areas. The surrounding communities depend on the Whin Estuary for their livelihoods, mainly finfish and shellfish harvesting. The Whin estuary supports a highly diverse fish community. Fish species of marine origin dominate the fish biota in the estuary. These include*; Liza falcipinnis, Liza dumerilii, Mugil bananensis, Mugil cephalus, Mugil curema, and Sardinella maderensis*. Oyster harvesting is the main shellfish-targeted fishery in the estuary. Other shellfish include mussels, shrimps, and some estuarine gastropods. Women are the main harvesters of the oysters whereas shrimp form part of the species fished by men in the estuary. There are about 80 women oyster harvesters in the surrounding communities (Atindana et al., 2019). There is somewhat dense mangrove vegetation surrounding the estuary, which is considered healthy relative to that of Densu and Narkwa. Active cutting of the mangroves occurs at a few sections for various purposes including trimming under electricity lines and for fuelwood. In 2014, the Western Region reported eight percent of people in Phase 2 category (under pressure) of food insecurity, thus communities around the Whin Estuary could be within a similar category.

2.1.4 Allahein Estuary (The Gambia)

The Allahein River estuary (Figure 4A) is an area of high ecological importance as it supports communities from The Gambia and southern Senegal, who are separated by the water body, which has crossing points either by boat or on foot during low tide (Anonymous, 2014). The communities of Kartong and Berending in The Gambia and others from Southern Senegal utilize the oyster and cockle resources for their livelihoods. Shellfishing in such communities creates employment, income, and revenue and provides food and nutrition security as well. Overexploitation of the oyster and cockle resources is a major challenge due to involvement of a large number of people harvesting these resources, in addition to the uncontrolled misuse of the mangroves.

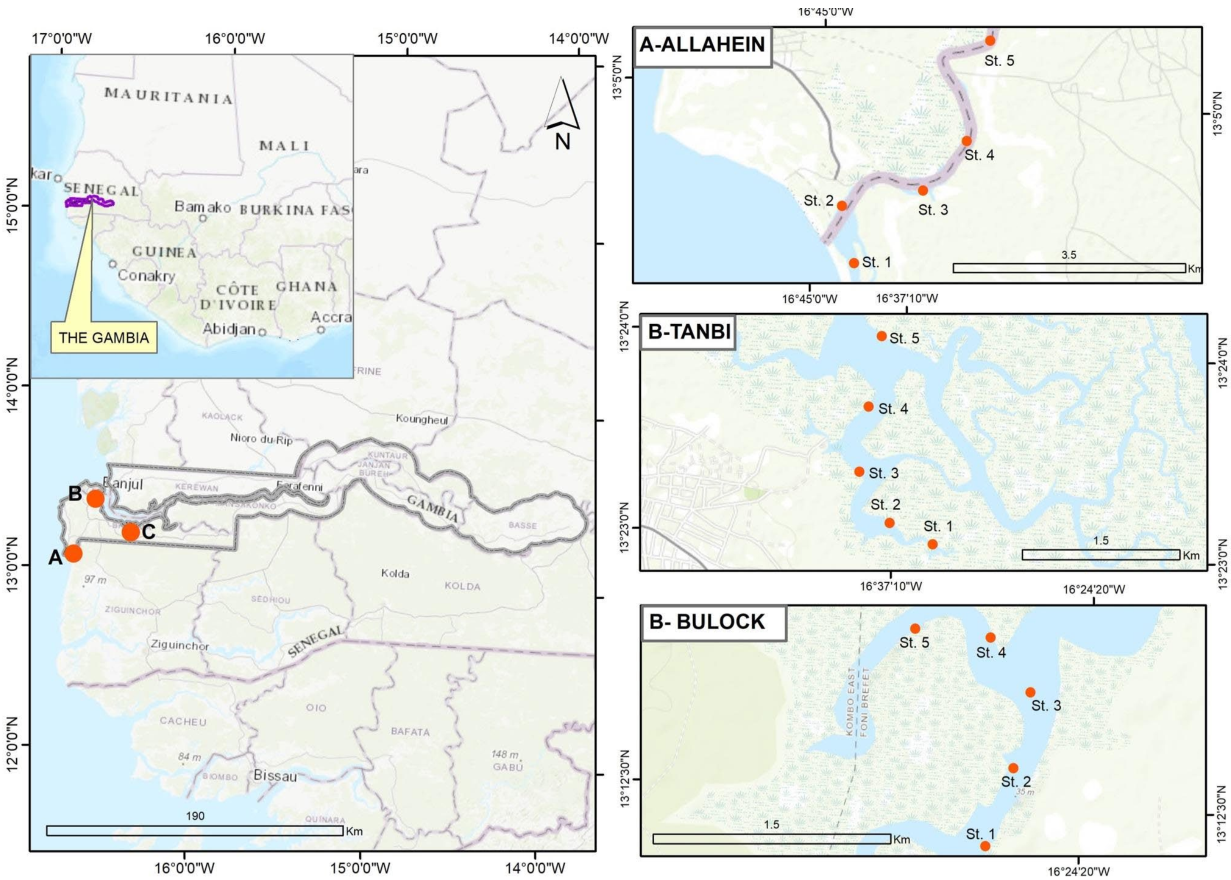


Figure 4: Map of The Gambia showing the selected sites and sampling locations at each site.

2.1.5 Tanbi Wetland National Park (The Gambia)

Tanbi Wetland National Park (Figure 4B) consists of mangrove swamps that front the ocean to the north and the Gambia River to the east and stretch from Banjul to Mandinari. It covers an area of nearly 6,400 hectares (of which mangroves make up 4,800 hectares). It was declared a RAMSAR site (No. 1657) in February 2007, and then gazetted as a national park in 2008 (DPWM, 2008). The impact of drought has caused several hydrological changes and ultimately changes in mangrove distribution in some areas (Diop et al., 2002). The key human activities in and around the park include shellfishing, vegetable gardening, and rice production. During the dry season (December to June), women, who are mainly of the Jola ethnic group, engage in oyster harvesting from the mangroves. Women shellfishers in this area have been given exclusive use rights to the oyster and cockle fisheries by the government of The Gambia and the shellfishers have authority to sustainably manage the shellfishery (MOFWR, 2012.) This is the first instance in sub-Saharan Africa for women shellfishers to be given such use rights by a national government.

2.1.6 Bulock Mangrove Area (The Gambia)

The Bulock mangrove area (Figure 4C) is in the West Coast Region of The Gambia, approximately 50 – 70 km from Banjul. The communities include Bulock, Sutu Sinjang, Ndemban Chapechum, Besse, and Berefet. There are large areas of mangroves along the Bulock-Bereft stretch, with numerous creeks, which are locally called "*bolongs*". The shallow water in these areas are important sources of fishing. Rice farming, vegetable gardening, and firewood collection provide key livelihood activities in the area adjacent to the mangroves. The coastal zone of some of this area is under threat due to anthropogenic human activities, mainly from mangrove cutting, resulting in physical loss of the ecosystem. Local grassroots efforts in Bulock and nearby communities are replanting mangrove saplings to help restore degraded areas.

2.2 Materials and Methods

Several methods were used as protocols to guide the research activities. Figure 5 shows UCC researchers collecting water samples.

2.2.1 Measurement of physico-chemical parameters

The hydrographic conditions were measured monthly for thirteen months from March 2021 to March 2022. The parameters measured were water temperature, dissolved oxygen (DO), salinity, and pH, determined *in-situ* using a multi-parametric water quality instruments checker (Horiba U-52 series). Triplicate measurements were taken at each of the five stations at each site. Turbidity (recorded in NTU - Nephelometric Turbidity Unit) was determined using the Hach DR 900 Colorimeter, which operates mainly on the principle of absorbance spectrophotometry. Data for monthly rainfall (mm) in the vicinity of the study sites were extracted from an online global climate database for the nearest meteorological data stations, for the period of the study where available (https://en.tutiempo.net).

Figure 5: Project research team conducting water quality assessments at the various project sites in Ghana and The Gambia.

2.2.2 Determination of Nutrient levels

2.2.2.1 Nitrate and Phosphate concentrations

Nitrate and Phosphate concentrations were also determined quarterly using the Hach DR 900 Colorimeter. The determination followed colorimetric procedures using powder pillow reagent; NitraVer®5 and PhosVer®3 for nitrate and phosphate, respectively.

Following the USEPA Powder Pillow procedure for determination of nitrate concentration, a sample cell or vial was filled up to the 10 ml mark with a replicate water sample collected from the sites, and one reagent powder pillow (NitraVer®5) was emptied into it and shaken vigorously for one minute, and then placed down for a five-minute reaction time. The formation of an amber color indicates the presence of nitrates, and after zeroing the instrument with a blank sample, the nitrate (NO_3^-) concentration (in mg/l) was determined at a wavelength of 355 nm (355 N, Nitrate HR PP). Figure 6 shows examples of color differences in the vials.

The procedure was similar for determination of phosphates (PO_4^{3-}) using reagent powder pillow (PhosVer®3). The sample was shaken vigorously for 30 seconds after adding the reagent and allowed a reaction time of two minutes. The occurrence of a blue coloration indicates the presence of phosphate, and the concentration (mg/l) was determined at a wavelength of 490 nm (490 P React. PP).

Blue - Presence of Phosphates | **Reference – No nutrients** | **Amber - Presence of Nitrates**

Figure 6: Color changes for the presence of nutrients in water samples upon reaction with reagent powder pillows.

2.2.3 *Determination of coliforms and E. coli levels*

2.2.3.1 Total and fecal coliforms

The samples were analyzed for the detection of total coliforms, fecal coliforms, and *Escherichia coli*. For the determination of total coliforms, isolation of bacteria by Membrane Filtration method was carried out using a modified procedure of Mulamattathil et al. (2014). Culture media of Eosin Methylene Blue agar (Oxoid), with Peptone Water (Oxoid) as recovery diluent were prepared. Petri dishes and other materials were sterilized by means of autoclaving along with all prepared media and petri dishes at temperature of 121°C, pressure of 15psi for 15 minutes. Volumes of 100 ml of water sample were filtered through sterile 0.45 μm pore size filter (Mixed Cellulose Esters, Merck Millipore) using a vacuum pump. The filtered membrane was aseptically placed up on plates using a sterile forceps ensuring that no air bubbles were trapped. The plates were inverted and incubated at 37°C for 48 hours. All colonies were counted and recorded as aerobic plate counts (colony forming units – CFU) (CFU/100 ml) for the sample.

Likewise, for the fecal coliforms, volumes of 100 ml of water sample were filtered through sterile 0.45 μm pore size filter (Mixed Cellulose Esters, Merck Millipore) using a vacuum pump. The filtered membrane was aseptically placed up on plates with sterile forceps ensuring that no air bubbles were trapped. The plates were inverted and incubated at 44°C for 48 hours. All colonies were counted and recorded as aerobic plate counts (CFU/100ml) for the sample.

2.2.3.2 Escherichia coli load

Colonies were plated with sterile inoculating wire by streaking onto eosin methylene blue agar plates. The plates were then incubated at 37°C for 24 hours (George et al., 2012). For *Escherichia coli* presumptive test, isolated colonies of about 2-3mm diameter exhibiting a greenish metallic sheen by reflected light and dark purple centers was identified as possible colonies of *Escherichia coli* (Oxoid.com, 2011).

Isolated colonies were inoculated into Oxoid SIM (Sulfite Indole Motility) medium, stabbing the needle approximately two-thirds of the way deep. It was incubated at 37°C for 24 hours or until growth was evident. To test for the presence of indole, five drops of Kovac's reagent were added to the top of the deep. A positive indole test was indicated by the formation of a red color in the reagent layer on top of the agar deep within seconds of adding the reagent (MacWilliams, 2009).

2.2.4 Determination of concentrations of heavy metals

The heavy metals assessed covered Lead (Pb), Chromium (Cr), Cadmium (Cd), Arsenic (As) and Mercury (Hg).

2.2.4.1 Preparation of water samples

With the determination of heavy metal concentration in the water samples, the sampling containers were prewashed with detergents, soaked, and washed in 10 percent nitric acid for 24 hours, rinsed thoroughly with double distilled water, and oven dried overnight. For dissolved water metal analysis, the samples were filtered and collected into 500 ml sampling bottles and acidified with 5 ml of nitric acid (HNO_3) to a pH below 2.0 according to EPA Method 3005. The samples were well labeled and kept under refrigeration until analysis. For dissolved metal analysis, water samples were directly aspirated into the atomic absorption spectrophotometer to determine the metal content.

2.2.4.2 Preparation of oyster tissue

To determine the concentration of the selected heavy metals in the oyster tissue, 1.0±0.01 g of sample oyster muscle tissue was weighed into a digestion tube. 10 ml of concentrated HNO_3 and 5 ml of concentrated H_2SO_4 was added to the sample and allowed the reaction to proceed. The sample was transferred into the digestion tube on a hot block digestion apparatus and heated at a temperature of 60-95 °C for 1-2 hours. The digestion tube was removed when the sample turned black, allowed to cool, and then added 1 ml of H_2O_2. The tube containing the sample was placed on the hot block digestion apparatus. H_2O_2 was added to the sample until it became clear, and the tube was removed from the block to cool finally. Deionized water was added and rinsed thoroughly and filtered through Whatman No. 42 filter paper quantitatively into a 100 ml volumetric flask. Deionized water was added to the 100 ml mark on the flask. The elements were then ready to be analyzed (Farrukh, 2012).

2.2.4.3 Determination of heavy metals

The concentration of heavy metals was measured using PINAAcle 900T Perkin Elmer Atomic Absorption Spectrophotometer. The concentration of Pb, Cr, and Cd were determined using flame atomic absorption spectrophotometer. As and Hg were measured using a flow injection analysis system – atomic absorption spectrophotometer (Hydride Generation Technique) and (Cold Vapor Technique) respectively. Air-acetylene gas was used as the source of fuel for Pb, Cr, and Cd while argon gas was used for As and Hg (APHA, 2005).

2.2.5 Measurement of morphometric parameters of the oyster populations

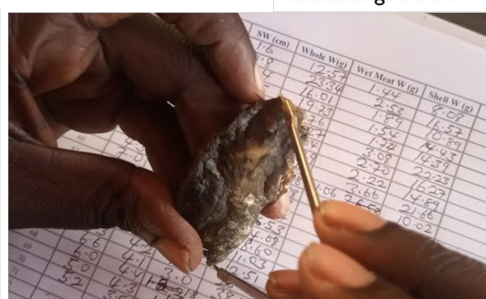
Samples of oyster were collected monthly from March 2021 to February 2022 for morphometric analysis. The parameters measured were the shell length (SL), shell height (SH), shell width (SW), whole weight (WW), and wet meat weight (WMW), shell weight (SWgt) and dry meat weight (DMW) which was carried out by oven drying for 36 hours at 105 degrees Celsius. Length measurements were taken in centimeters (cm) and weights measured in grams (g). Shell length metrics followed Galtsoff (1964) as shown in Figure 7.

Using improvised lab at TRY office (Gambia) for morphometric data collection

Taking data at the UCC lab

Shell Weight data

Oven drying oyster samples



Taking morphometric measurements

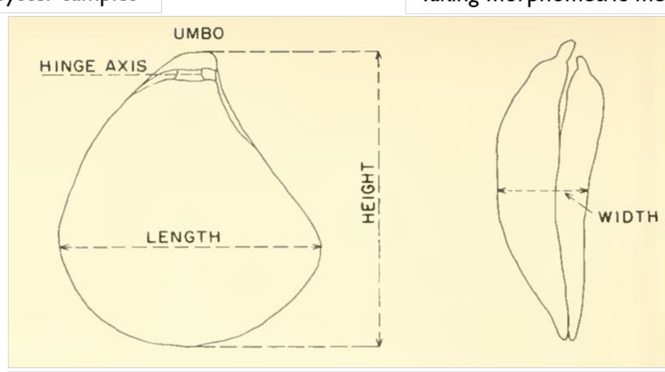


Illustration of morphometric dimensions measured; from Galtsoff (1964)

Figure 7: Research team undertaking laboratory work on oyster morphometrics data collection in Ghana and The Gambia.

2.2.6 Determination of Condition Index

Condition indices of the oysters from the different water bodies were calculated using the following formula (Lawrence & Scott, 1982):

Condition Index = dry meat weight in g X 100 / internal cavity volume in cm^3

2.2.7 Determination of maturity sizes

The oyster specimens were examined for gonadal developmental stages microscopically. The maturity and sex of the oysters were determined microscopically by making smears of oyster gonads on a slide observing under a compound microscope (Motic BA310). The female gonads appear oval or pear shaped, while the male gonads show highly condensed dotted shapes. Specimens were categorized as mature (male or female) and immature and preserved for a later histological examination. The maturity size (Lm_{50}) was determined by fitting sigmoid curve to the cumulative frequency of the various shell height/length classes in the sample and determining the length at which 50 percent of the population matures using a trace line from the 50 percent mark on the frequency (Y)-axis to the curve and tracing the corresponding size on the shell height (X) – axis.

2.2.8 Analyses of sex ratios

Monthly proportions of individuals belonging to the different sexes were analyzed, and sex ratios determined. Figure 8 shows differences between male and female gonads under a microscope.

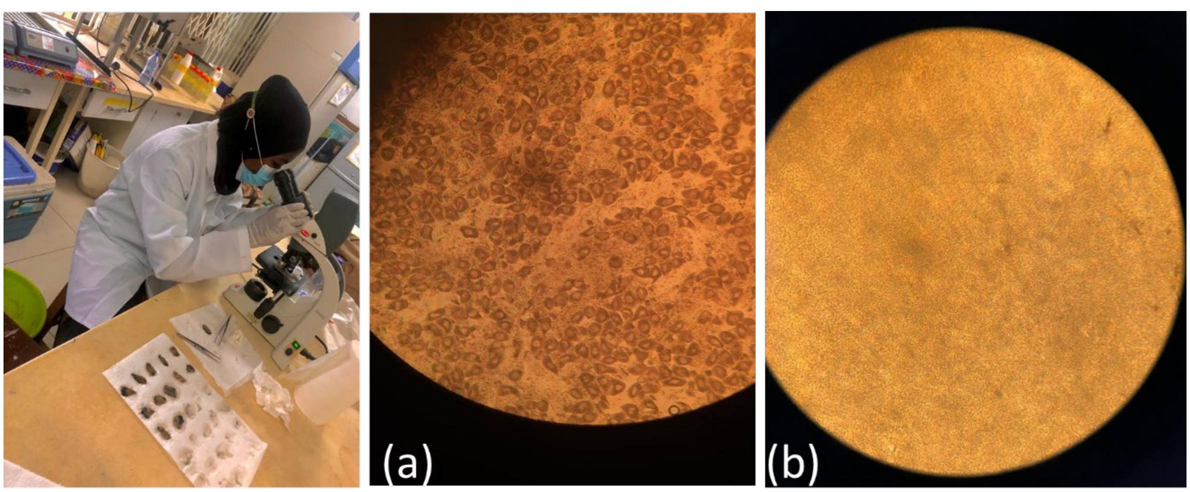


Figure 8: Laboratory work - A graduate student and research team member examining the sexes of oysters; (a)female and (b) male gonads.

2.2.9 Histological procedures for examination of gonadal development

Sex and developmental state of oyster gonads were determined by standard histological procedures (see Figure 9) in conjunction with light microscopy. Quarterly samples of 20 adult oysters were obtained, each from three sites in both Ghana and The Gambia for the study. Oysters were shucked and the 'gonads' (visceral mass) cut at the dorsal and ventral ends with a surgical blade prior to fixing them in a Bouin's solution for 24 hours to enhance the infiltration of the fixative. The fixed specimens were washed thoroughly and preserved in 70 percent ethanol.

The samples were processed by standard histological techniques involving dehydration with increasing concentrations of ethanol to absolute (100 percent), clearing with chloroform and infiltration with molten paraffin wax using an automatic tissue processor (Shannon Elliot SE 400). Successively, the processed tissues were embedded in paraffin wax, and fixed on wooden holders for sectioning with a rotary microtome (Bright 5040). Six 'serial' sections were made from each specimen (i.e., two successive sections from three different portions along the gonad were cut to get a good representation of gonadal development).

Tissue sections were cut at 6 - 10 μm thickness and mounted on microscope slides. Duplicates of each sectioned specimen were kept, as backup. The sections were subsequently stained with Ehrlich's haematoxylin and counter-stained with eosin and cover-slipped. Well dried cover-slipped slides were examined microscopically at magnifications ranging from 50 - 400 (Osei, 2020; Yankson, 1996) using Motic BA310 Compound Microscope in conjunction with Motic Image Plus 2.0 software ran with a computer for observations and photomicrographs.

Quarterly gonadal indices of oysters from the various sites were calculated by a modified version of Chipperfield's (1953) index of gonad maturity scheme by ranking the different gametogenic stages as follows:

Stage I (Developing) – 1;

Stage II (Ripening) – 2;

Stage III (Ripe) – 3;

Stage IV (Spawning) – 2;

Stage V (Reabsorption/ Redeveloping) – 1.

Individual scores assigned to gonad conditions were used to estimate the monthly mean gonad index according to the equation: Mean Gonad Index (GI) = $\Sigma gn/ N$ (Krampah et al., 2016; Osei, 2020), where g = rank of the stage, n = number of individuals assigned to a stage and N = sample size.

Figure 9: Laboratory work - research team processing oyster samples and carrying out histological procedures on oyster samples from the various sites in Ghana and The Gambia.

2.2.10 Determination of growth and mortality parameters of the oyster populations

Adopting the length-structured model approach, the monthly shell height data were used to fit the von Bertalanffy growth model for the growth parameters (K and $L_{inf.}$ and t_0) using the TropFishR package in the R programme (Figure 10). The total mortality (Z) of the oyster population was estimated by the length converted catch curve (Pauly, 1983; Munro, 1984) while the instantaneous natural mortality (M) was estimated from Pauly (1980) using the empirical equation below (with inputs from the growth parameters), where T is the mean annual water temperature determined for each of the six sites in Ghana and The Gambia:

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

Fishing mortality (F) was obtained from the relationship: F = Z – M (Gulland, 1971). All estimates were computed using the R program.

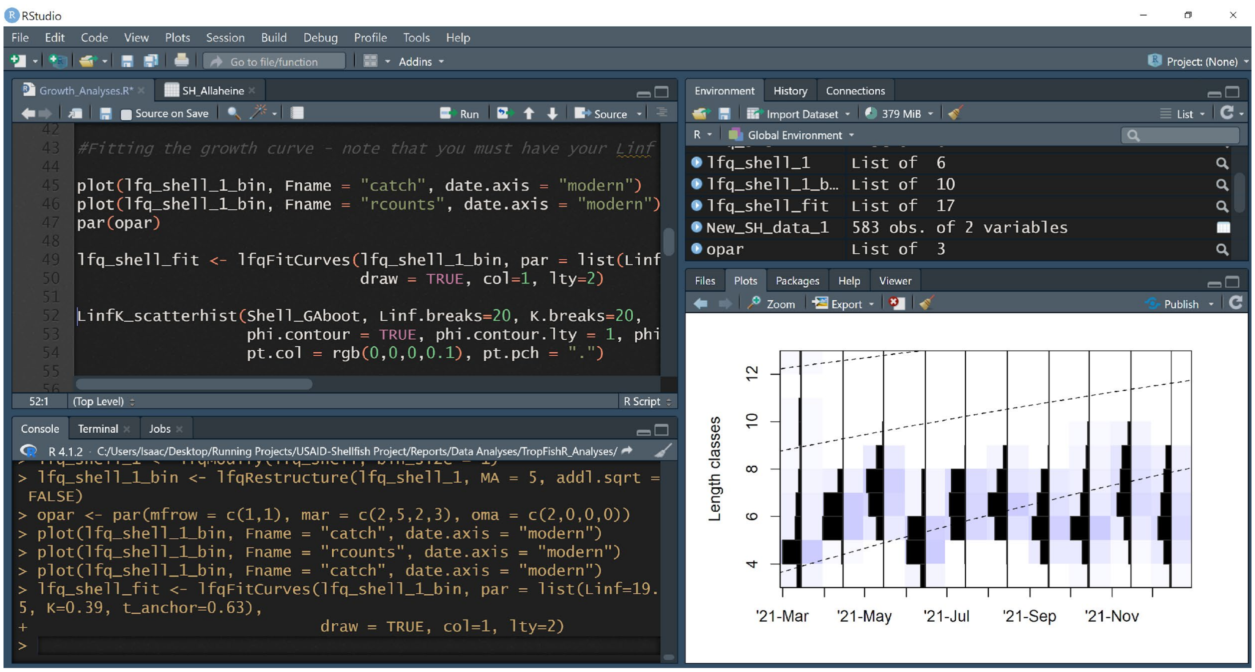


Figure 10: Interphase of R showing some codes in TropFishR used for analyzing the length-frequency data of the oysters for estimation of the growth and mortality parameters.

2.2.11 Exploitation ratio of the oyster stocks

The exploitation ratio (E), which is a measure of the level of exploitation of the oyster fishery was calculated by the equation: E = F/Z (Gulland, 1969). A combination of the growth and mortality indices were used to describe and compare the fishing pressure among sites.

2.2.12 Assessment of Catch Per Unit Effort (CPUE) of the oyster fisheries

Catch and effort data were collected at all sites through a participatory data collection approach involving shellfishers in Ghana and the Gambia (with members of Try Oysters Women Association). The Gambia catch and effort data collection was carried in 2021 while the Ghana data were collected in 2022. At Allahein, the fishery was closed for the whole of 2021 and therefore data on catch and effort could not be collected. Also at Densu, the fishery was closed in November 2021 and opened in April 2022, hence data was collected for only May 2022 prior to completion of this final report. Catch and effort data were used to estimate the catch per unit effort and compared across sites as a metric for comparative analyses of fishing pressure among the sites.

2.2.13 Estimating harvesting intensity at the sites

The harvesting intensity was estimated for each site using a combination of data from the key informant interviews (KIIs) and focused group discussions (FGDs) conducted and described in sections 2.2.14 and 2.2.15, geo-spatial mapping data for ecosystem size and mangrove extent, and field assessment of linear extent of shellfishing area adjacent to mangroves. Data from the KII and FGDs and the other assessments used to estimate the fishing pressure or harvesting intensity were the (1) number of persons (harvesters) (2) size of fishing area, (3) distance to and from harvesting grounds, (4) time spent harvesting, and (5) frequency of harvesting. The size of fishing area, distance to and from harvesting grounds, and time spent harvesting are influenced by the size of the ecosystems, thus, ecosystem size, both water area and harvestable mangrove area inclusive, was used as a proxy in approximating an index of fishing pressure at the sites. The index of fishing pressure was estimated using the formula [(H/A)/1000] where H is the total number of women harvesters, and A is total shellfishing area.

2.2.14 Assessment of the socioeconomics of the oyster fisheries

The socio-economic assessment was carried out in Ghana (Densu, Whin, and Narkwa) and The Gambia (Allahein, Bulock, and Tanbi) to understand the socio-economic status of women involved in shell fishing. A structured questionnaire (See Appendix 1) was administered to individual shellfishers using the KoBoToolbox mobile application. It solicited information on poverty, wealth (measured based on house structure), income, livelihood dependency, alternative livelihood options during lean/closed shell fishing seasons, and women empowerment. The interviews were conducted at each site with shell fishers that were available and willing to participate in the interviews. Informed consent was sought from the respondents and were assured of confidentiality in the entire study. In all, 120 individual interviews were conducted in the study areas and the data was cleaned and analyzed using Minitab version 20 software. All the scores from the dimensions were summed to obtain the overall score for each of the six indicators. A normality test was performed to see if the sample data came from a population with a normal distribution. A correlation analysis was used to evaluate the relationship between the indicators.

2.2.15 Assessment of the governance regimes and management modalities of the oyster fisheries

To solicit site-specific information on the shellfishery, governance regimes, and management structures, FDGs were conducted with key informants (KIs) at all the six sites in Ghana and The Gambia (Figure 11). The inclusion criteria for participants of the FGD were (1) should be part of the leadership (or elderly person) of shellfishers association or group in the community, and (2) should be engaged in the fishery for not less than fifteen years. Government officials at the sites (mainly fisheries officers) were also included in the discussions. The discussions were guided by the inductive content analysis approach (Lincoln & Denzin, 2003). Issues discussed were grouped into major themes, broadly covering the scope and state of the shellfishery, access, harvests, condition of mangroves, governance, and management regimes, among others (See Appendix 2). The interviews were transcribed verbatim and the transcripts were studied. Subsequently the data was organized into main sections similar to the sections in the instrument. Both similar and different views and experiences on the subject were identified under sub-themes to aid comparison.

Figure 11: A focus group discussion (FGD) session at Bulock.

The details of the wealth and women's empowerment indicators are explained below:

Poverty indicator – was adapted from the poverty probability index. (https://www.povertyindex.org/). Shellfishers were asked seven questions including the number of members of their household, the consumption of chicken, eggs, and beef in the past month, the use of cooking gas or electric equipment for cooking, ownership of refrigerator, fan, and television. The sum of scores ranged from 0 to 7, thus, the higher the score, the wealthier the household and vice-versa.

Shellfishers' wealth measure by household structure – was determined by posing questions on the type of materials used in the roofing and walls of the house/dwelling of the shellfishers. The sum of scores ranged from 0 to 4, thus, the higher the score, the wealthier the household.

Shellfishers' household income – was determined by inquiring from the shellfishers how much their household earned in an average week from all productive activities/livelihoods over the last year. Six categories of earnings were presented ranked from one to six. The higher the score, the wealthier the household.

Livelihood dependence on shellfisheries – was determined by inquiring from the shellfishers how much their household income was from shellfishing-related activities over the last year. Four proportions were presented ranked 0 to 3. Shellfishing dependency was higher with a higher score.

Women Shellfishers' Empowerment score was adapted from the "Women's Empowerment in Agriculture Index and Women's Learning Initiative". It measures the roles and extent of women's engagement in the agriculture sector in five domains; 1) Production: Decision making on shellfishing, 2) Resources: Access to and decision making of assets and credit, 3) Income: Control over use of income, 4) Leadership: Group membership, and 5) Time: workload from shellfishing.

The overall indicator of shellfishers' wealthiness at each site was measured as a sum of the average scores on the poverty index/indicator, wealth measured by household structure, household income, and livelihood dependence on shellfisheries. The higher the score, on a scale of 1-20, the wealthier the shellfishers of the respective site.

For empowerment, scores of the first four (1-4) dimensions were summed in addition to a measure of their workload (+/- 10.5 hours; if less than 10.5 hours was spent on shellfishing in a day, then workload was adequate, otherwise excessive) to get an overall indicator of women shellfishers' empowerment in each country. The higher the score on a scale of 0-14 and the adequacy of their workload, the more empowered they are.

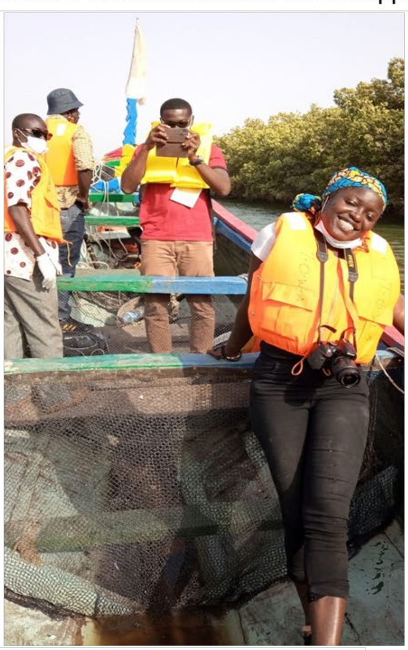
Data collection was carried out to the extent practicable with the participation of shellfishers (Figure 12).

2.2.16 Data analyses

All data were cleaned, and unusual values recorded in the physicochemical data suspected to have been caused or influenced by error in the functioning of water quality checking equipment were excluded from the analyses. The data were analyzed for frequencies, means, modes, and trends, and presented in graphical and tabular forms. The concentrations of heavy metals in the oyster tissues and water between sites and among countries were analyzed and compared to WHO standards. Data (colony counts) of coliforms were analyzed for means on each quarterly sample over the study period. Quarterly coliform concentration in oyster tissue were pooled and correlated with pooled rainfall data for the sites.

Coordinator of TRY Oysters supporting to determine nutrients in water samples

Women Shellfishers from Bulock supporting in collection of oyster samples



Member of TRY Oysters supporting field work

A member of Densu Oyster Pickers Ass. supporting to collect oyster samples

Figure 12: Participatory research - shellfishers and partners participating to support the site-based research with hands-on activities.

2.3 Potential impact of the COVID-19 Pandemic on the Study

The study was carried out during the period when the COVID-19 pandemic influenced the food systems of the world at all levels, including production, trade, and value chains due to restrictions on gatherings, movement, travels, and lockdowns. Fisheries value chains, and shellfish value chains and trade were not exceptions. Especially for a country like The Gambia where the tourism and hospitality industry is a major driver of the economy and livelihoods, the impacts of the pandemic possibly influenced some interview responses such as issues relating to livelihoods, production, income and poverty during the socio-economic survey in the study. Other indirect impacts of the pandemic on the study included delays in procurement of reagents and consumables for the laboratory work due to challenges with importation of goods to Ghana.

3. RESULTS

3.1 Trends in water quality parameters

Observations on the general trends for the various water quality parameters are presented in Figures 13-18 for Ghana and The Gambia.

3.1.1 Physico-chemical parameters

3.1.1.1 Depth

The coastal water bodies of Ghana and The Gambia included in the study had variable depths. Whereas depth was characteristically different at the sampling stations in each water body, there was a marked difference between the systems of Ghana and The Gambia. The Gambia systems were generally deeper than the systems of Ghana, averaging 2.80 m and 0.75 m, respectively. The Tanbi estuary had the deepest mean depth, with Station 1 having the largest mean depth value. The Whin estuary is the shallowest among the systems studied, averaging 0.64 m. The distribution of depths at the sampling stations as recorded over the study period are shown in Figure 13. A summary table of the mean depths with mean, minimum and maximum values is presented in Table 2.

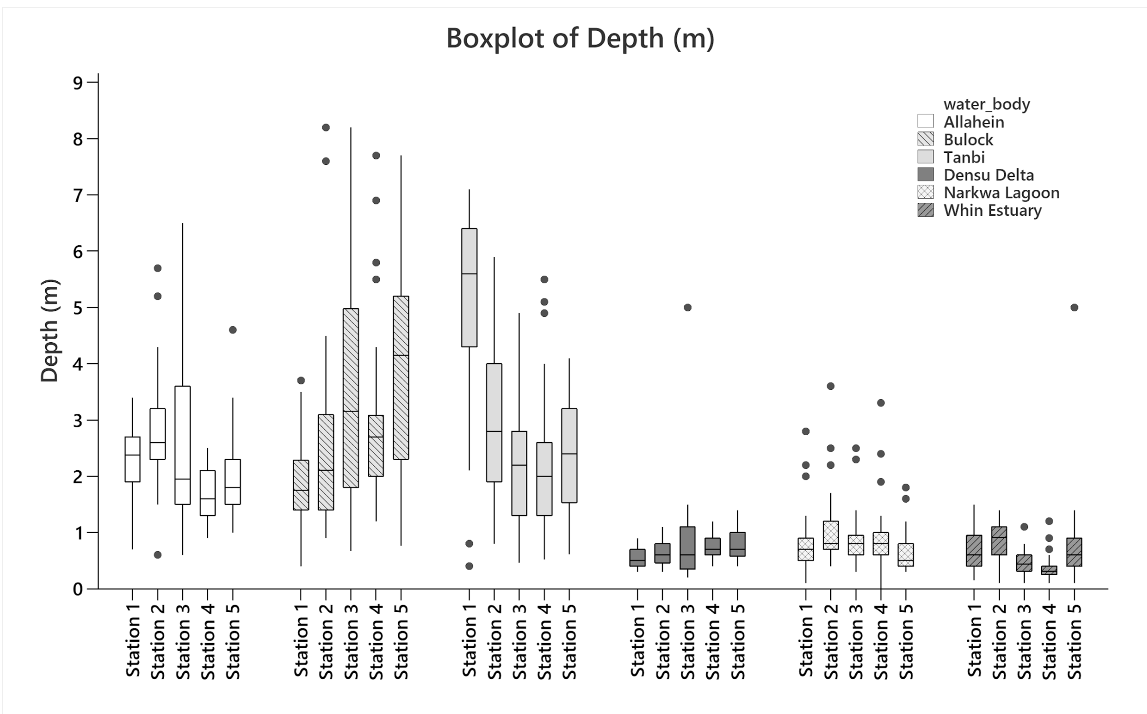


Figure 13: Box plot of the range (distribution) of water depth at the sampling stations in the six water bodies in The Gambia and Ghana from March to December 2021.

Table 2: *Mean depth of the six waterbodies studied in The Gambia and Ghana.*

Water Body	N	Mean Depth	SE Mean	Minimum	Maximum
Allahein	150	2.38	0.09	0.60	6.50
Bulock	135	2.92	0.14	0.67	8.20
Tanbi	150	3.09	0.14	0.40	7.10
Densu	150	0.72	0.04	0.20	5.00
Narkwa	148	0.86	0.05	0.00	3.60
Whin	150	0.65	0.04	0.10	5.00

3.1.1.2 Rainfall

The monthly rainfall data (Figure 14) shows the peak of Ghana's rainfall in 2021 in June (Narkwa and Densu) - July (Whin) and another peak in September-October with the highest rainfall occurring at Whin. At the sites in Gambia, the peak of the rainfall occurred in August-September 2021, with Tanbi and Allahein having equal intensity of rainfall as the data were obtained from the same recording station (Yundum-Banjul); data for Bulock were not available.

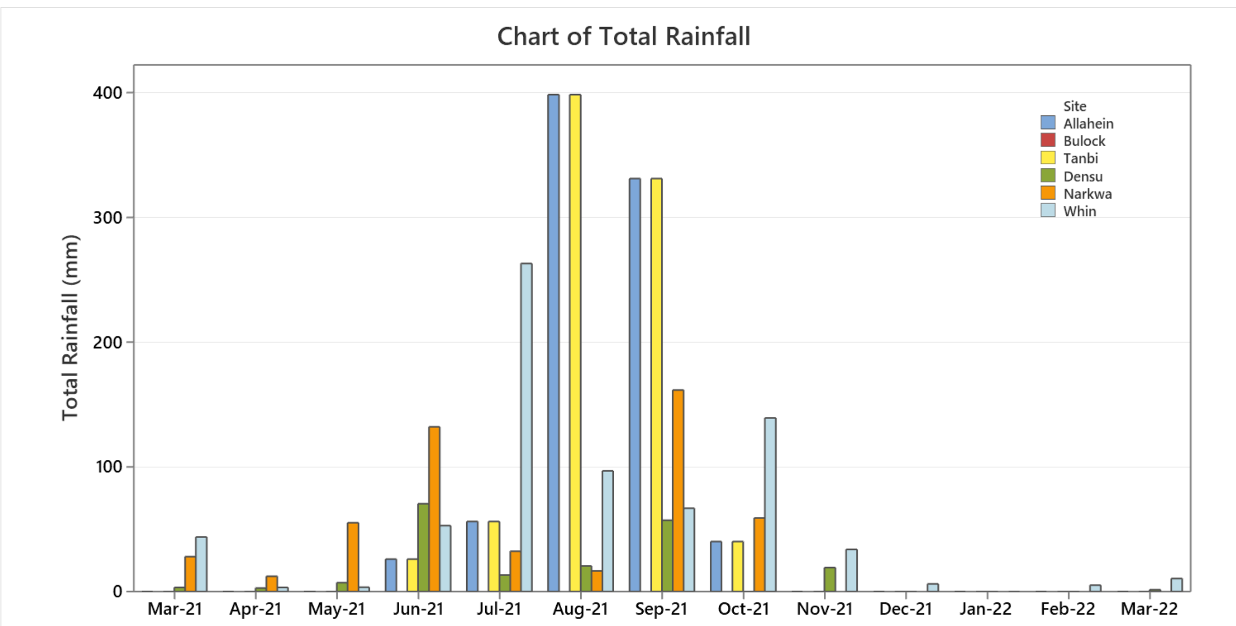


Figure 14: Monthly total rainfall at the study sites in Ghana and The Gambia from March 2021 to March 2022. Empty bins represent either no rainfall or no data.

3.1.1.3 Water temperature

Water temperature ranged from about 24 °C to 34 °C in the ecosystems studied. There were monthly variations in temperature for all six sites (Figure 15). The trends in temperature changes in the ecosystems were similar for the systems within countries but appeared to be opposite between the two countries. For The Gambia, the general trend increased progressively from a low of about 27 °C in March 2021 to a peak of about 32 °C in September 2021, then declined sharply to the lowest recorded water temperatures recorded for The Gambia (25 °C) from December 2021 to February 2022. Ghana had a reverse of this trend, beginning at a peak temperature of about 33 °C in March 2021, followed by a progressive decline with lowest temperatures in July followed by a gradual increase to March 2022.

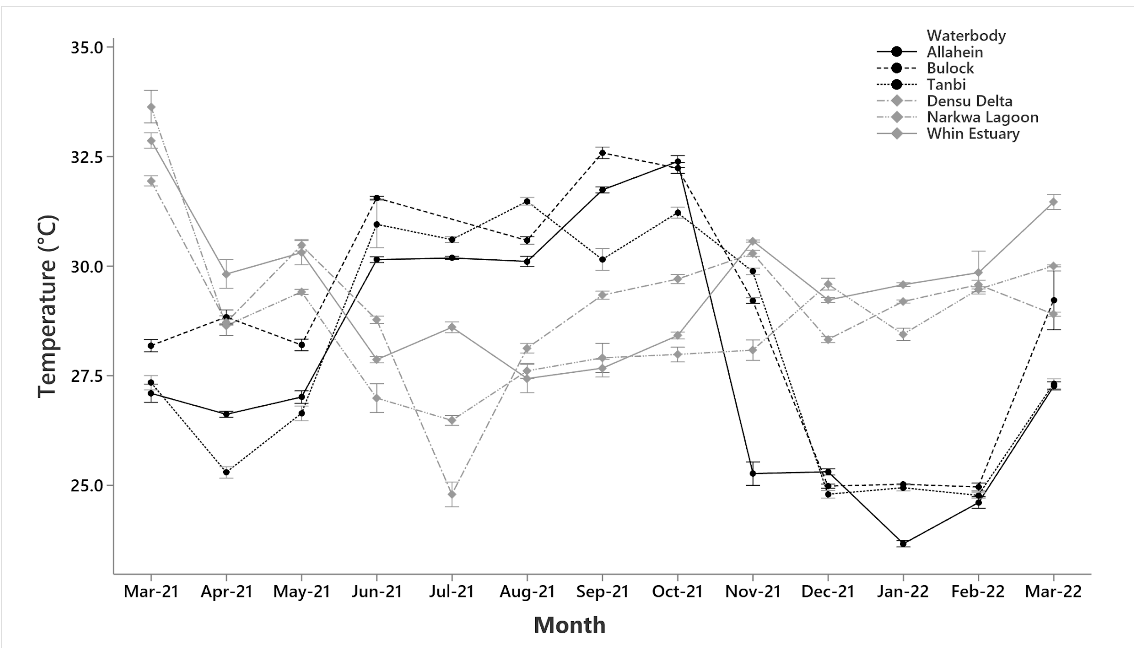


Figure 15: Monthly mean temperature variations in the six water bodies in Ghana and The Gambia from March 2021 to March 2022.

3.1.1.4 Salinity

The six systems studied had distinct salinity regimes for the two countries (Figure 16). Salinity levels in the ecosystems of The Gambia were generally higher with very minimal variations at each site within a month's sampling, whereas those for Ghana were relatively lower, with a wider salinity range for each month – this is depicted by the lengths of the error bars for each mean. Average salinity in The Gambia ecosystems ranged from about 20 ppt to 42 ppt. Average salinity recorded in the Ghana ecosystems ranged from near freshwater (approx. 0 ppt) conditions to 36 ppt. The trend in salinity for The Gambia ecosystems appeared to be stable from March to June 2021, after which there was a steady decline in salinity until September 2021, followed by an increase until March 2022. There was generally a somewhat haphazard trend for the Ghana systems although with a quite identifiable trend of increase from March to April-May 2021, then a sharp dip at all sites in June 2021. Following that were very dissimilar salinity recordings and trends for the three sites in Ghana through the months of July to November, but all Ghana sites showed an increase from November to January 2022, and fluctuations up to March 2022.

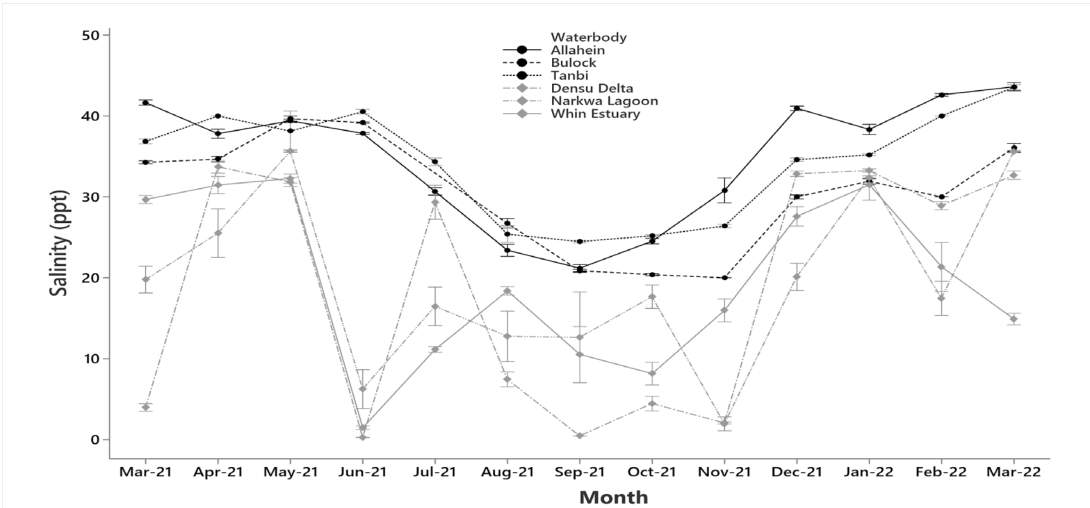


Figure 16: Monthly mean salinity variations in the six water bodies in Ghana and The Gambia from March 2021 to March 2022.

3.1.1.5 Dissolved Oxygen

Dissolved oxygen concentrations in the systems studied ranged from an average of about 3 mg/l to 10 mg/l. Months with missing data were data excluded mainly due to suspected equipment errors in the measurement. The trends in DO variations in the systems were close for many sampling months but significantly different levels were observed between the Ghana and The Gambia systems at certain periods of the year, such as between November and December, 2021. There were observable hikes in the months of April and May 2021 for The Gambia ecosystems and in December for the Whin estuary and Narkwa lagoon in Ghana (Figure 17).

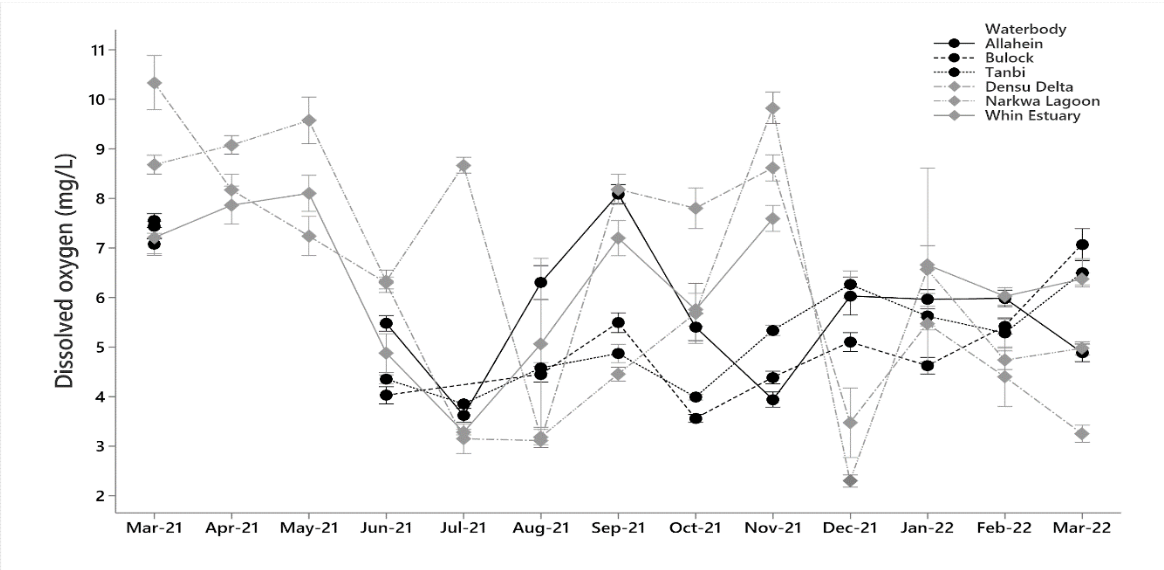


Figure 17: Monthly mean variations in dissolved oxygen concentration in the six water bodies in Ghana and The Gambia from March 2021 to March 2022.

3.1.1.6 pH

The pH ranged from an average of about 6.7 to 10 for all systems (see Figure 18). The trends in pH across the sampling months were largely similar for the ecosystems within each country. The systems of The Gambia experienced a general decrease in pH from March to May 2021, and a significant rise in June but became stable between 7.5 and 7.8 from July 2021 to March 2022 in all Gambian systems. For the systems in Ghana, the trend was oscillating between 6.7 and 10 in similar directions for most of the study period, except for May 2021 where there was a marked dispersion among the sites. Generally, the pH in the Ghana systems was higher than in The Gambian waters from November 2021 to March 2022.

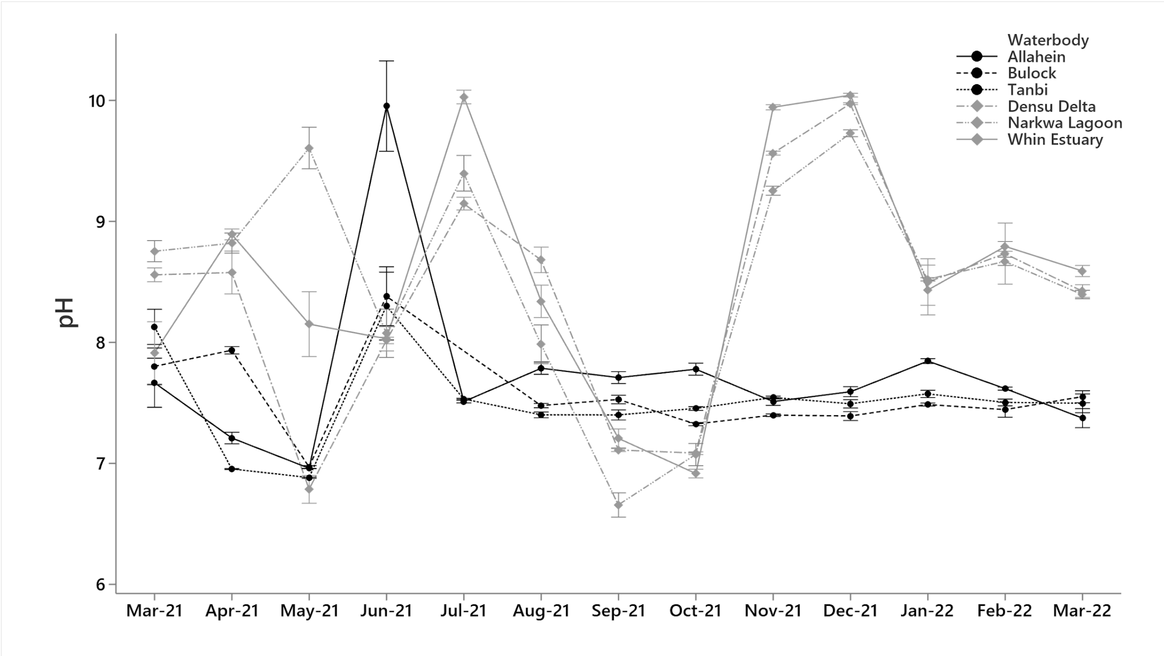


Figure 18: Monthly mean pH variations in the six water bodies in Ghana and The Gambia from March 2021 to March 2022.

3.1.1.7 Turbidity

There were visible differences in the turbidity levels in the systems studied, particularly among Ghana's three sites (Figure 19). The turbidity of Allahein, Bulock, and Tanbi in The Gambia was generally very low and quite similar throughout the entire study period, ranging from about 2 to 15 NTU. Relatively higher turbidity levels were recorded in the Ghana systems with a wider range of about 0 to 155 NTU in June, 2021. Months with missing data were data excluded mainly due to suspected equipment errors in the measurement.

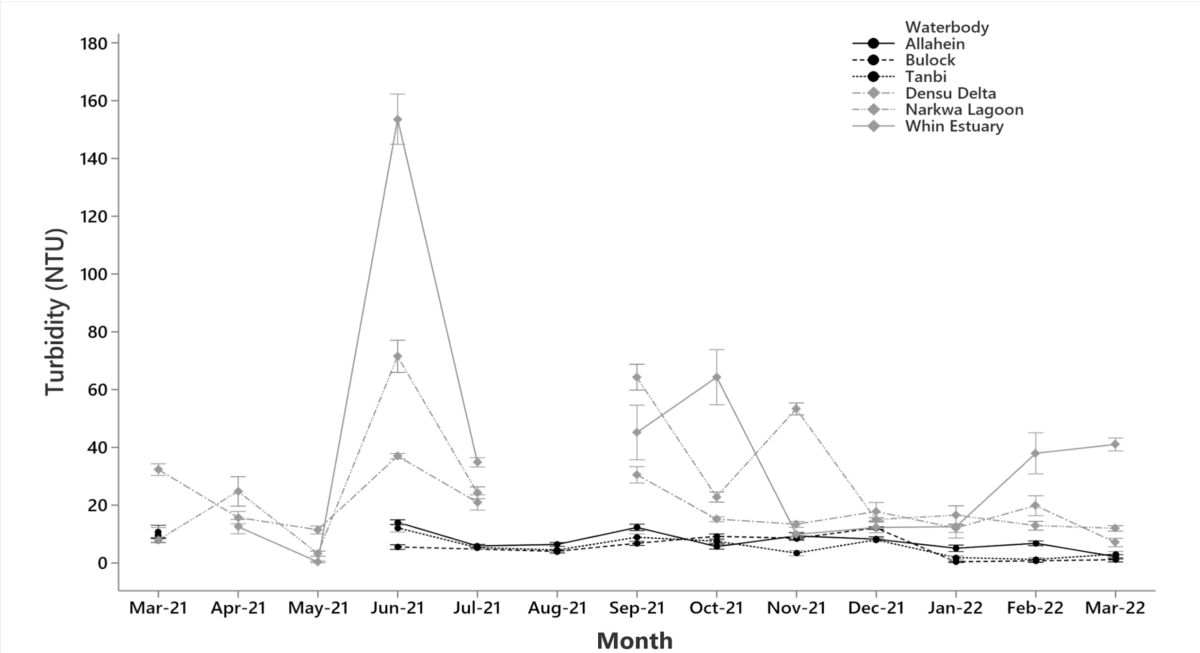


Figure 19: Monthly mean turbidity variations in the six water bodies in Ghana and The Gambia from March 2021 to March 2022.

3.1.1.8 Nitrate and Phosphate Concentration

There were varying concentrations of nitrates and phosphates in the six water bodies studied and for the different sampling quarters (Figure 20 and Figure 21). The levels of the nutrient were benchmarked against the optimum limits of 0.1 mg/l phosphate and 1.0 mg/l nitrate reported as the suitable levels for primary productivity in estuaries and other coastal ecosystems (NOAA/EPA, 1988). Nitrates were high in all systems in June and excessively high in the Gambian waters in September with the highest in Allahein, but drastically reduced levels in December 2021, and a progressive increase again in March 2022.

Phosphate levels however were high (above the 0.1 mg/l optimum level; NOAA/EPA, 1988) in all systems in the first three quarters (June, September, December) of sampling, with the highest levels recorded in Bulock. The missing data for March 2021 was due to unavailability of reagents for analyses as a result of COVID-19 related challenges in procurement of the reagents.

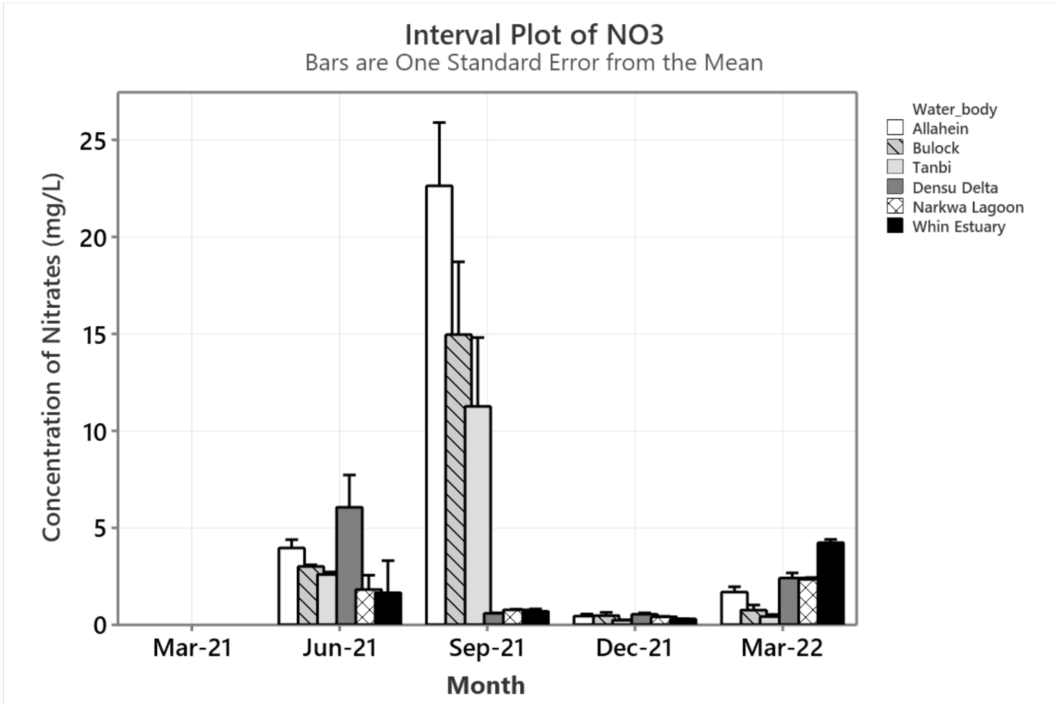


Figure 20: Nitrate concentrations in the six water bodies studied in Ghana and The Gambia from June 2021 to March 2022.

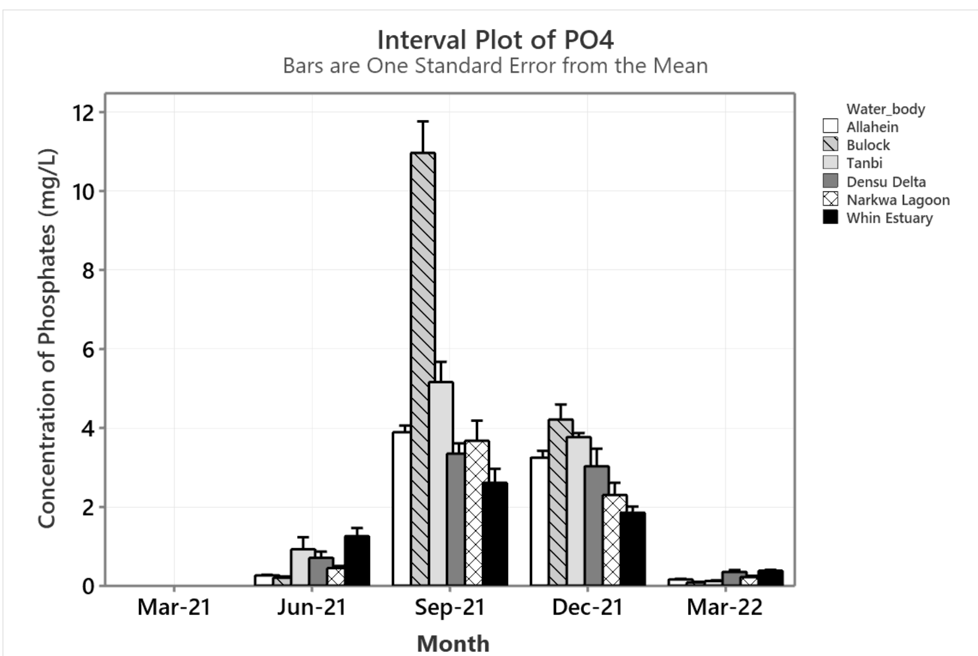


Figure 21: Phosphate concentrations in the six water bodies studied in Ghana and The Gambia from June 2021 to March 2022.

3.2 Occurrence and levels of coliforms and heavy metals

3.2.1 Total, fecal and coliforms and Escherichia coli levels

Total coliform includes *Escherichia, Klebsiella, Citrobacter* and *Enterobacter*, while fecal coliform includes *Escherichia and Klebsiella*. *Escherichia coli* is particularly of global health concern. The concentration of total coliforms, fecal coliforms and *E. coli* recorded in the waters at the sites are presented in Figure 22. Total and fecal coliform levels in water were compared to the US National Shellfish Sanitation Programs' approved standards for total coliform (70 CFU per 100 ml) and fecal coliform (14 CFU per 100 ml) in the waters of shellfish growing areas (NSSP, 2019). Data for March 2021 were excluded due to delays in the procurement of culture media and other reagents, which compromised the quality of the sample. In general, higher total coliform count was recorded at the sites in Ghana than The Gambia, although the levels were within the 70 CFU per 100 ml approved standards. Similarly, the levels of fecal coliform generally remained below the 14 CFU per 100 ml permissible level in most quarters at all sites, except in the June 2021 quarter where it reach 14 CFU per 100 ml at all sites in Ghana, and around 15 CFU per 100 ml in the September 2021 quarter in the Tanbi. *E. coli*, levels were very low in the waters, reaching virtually 0 CFU/100ml in some quarters.

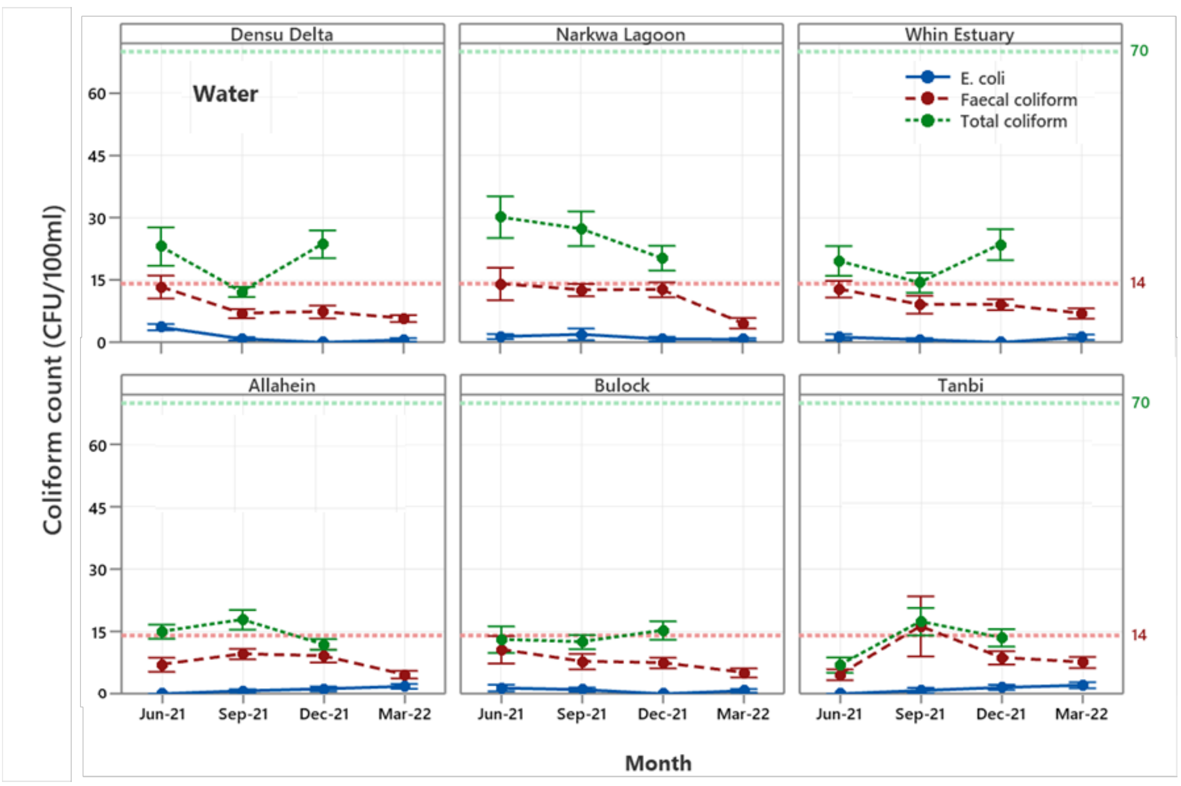


Figure 22: Mean colony count of total, fecal coliforms, and E. coli in the water bodies sampled from June 2021 - March 2022. (straight red dotted lines are safe threshold for fecal coliforms)

The total and fecal coliform levels in the oyster tissues (Figure 23) showed varied levels across different quarters at the different sites. The highest fecal coliform levels at Densu and Narkwa was recorded in June 2021, and in Allahein in September 2021. The highest observed total coliform level was in September 2021 in Allahein, and all coliform levels were lowest in March 2022. Like the water, *E. coli* levels in the tissues were also very low, reaching virtually 0 CFU/100ml in at the Ghana sites in nearly all quarters except in June 2021 in Densu. Similarly, there were low *E. coli* levels at the Gambia sites except in Tanbi where the concentration reached 8 CFU/100ml, the highest *E. coli* level recorded in oysters in the study. No coliforms were detected in Densu oysters in December 2021 and less than 1 CFU/100ml in March 2022.

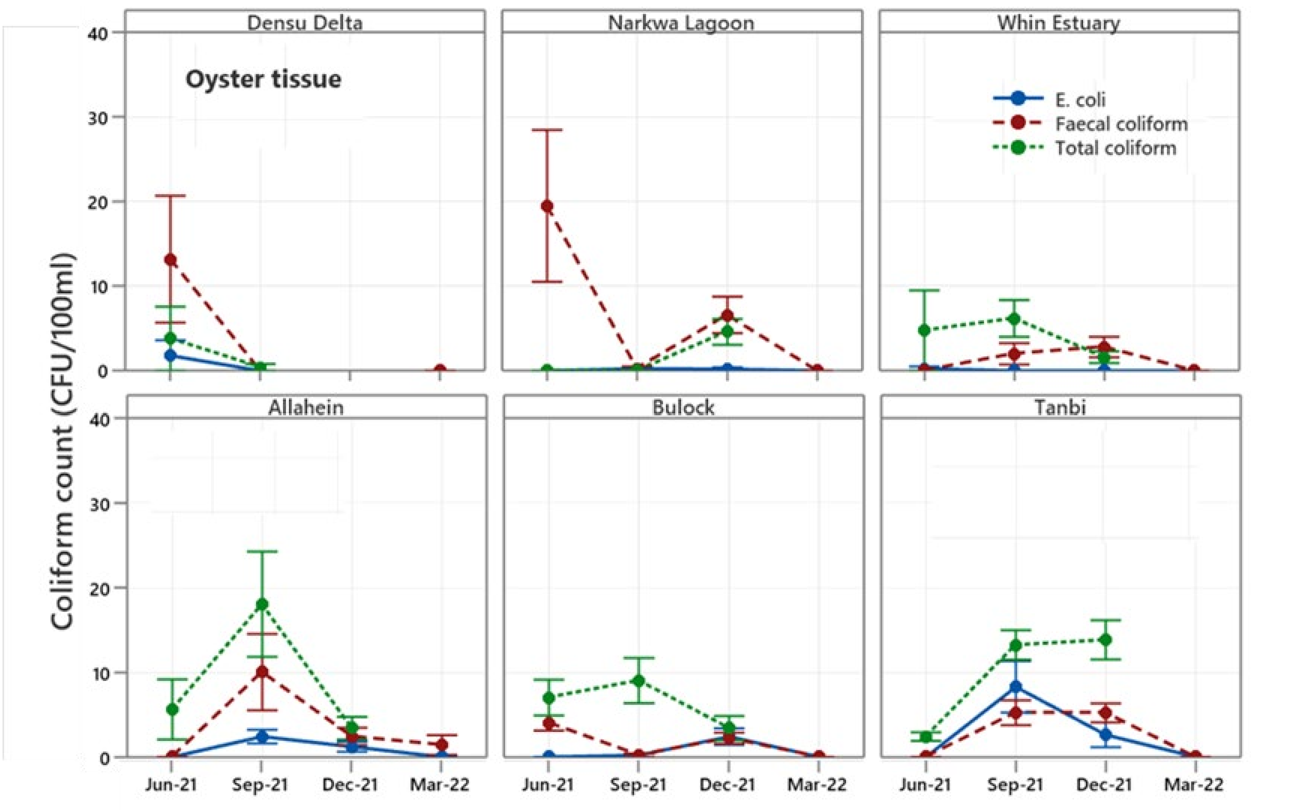


Figure 23: Mean colony count of total, fecal coliforms, and E. coli in oyster tissues sampled from June 2021 - March 2022.

3.2.1.1 *Escherichia coli* load-rainfall relationship

Local precipitation at the sites was correlated with the *E. coli* concentrations in oyster tissues across the study period (Figure 24). *E. coli* was of interest as it remains the fecal coliform with high public health concern. There was a fairly strong positive correlation ($r = 0.69$; $R^2 = 0.47$; $p = 0.002$) between total rainfall and the concentration of *E. coli* in oyster tissues in the estuarine systems studied. There was a unit of incremental change in *E. coli* concentration (CFU) with an increase of 0.013 units (mm) of rain.

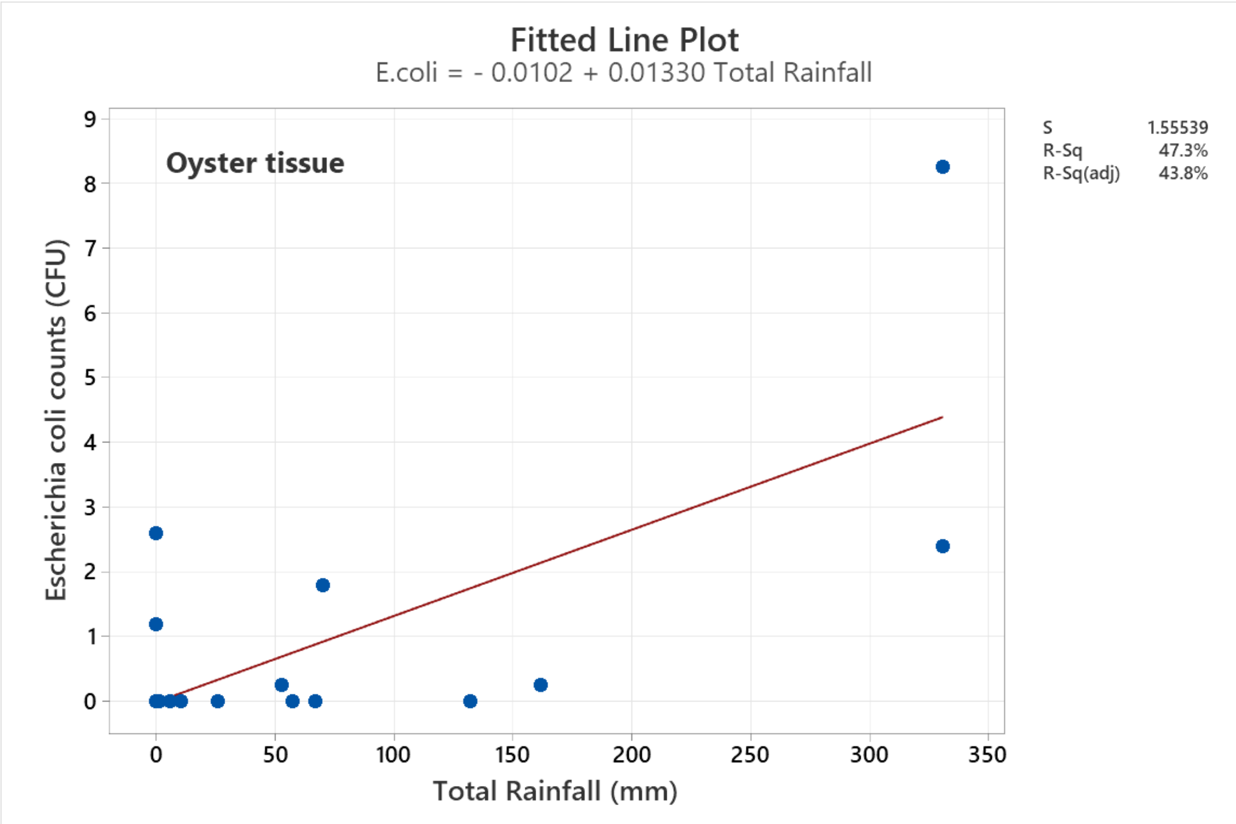


Figure 24: Correlation of Escherichia coli concentration in oyster tissue and rainfall for pooled data from all sites.

3.2.2 Concentration of heavy metals

Heavy metal concentrations obtained from the analytical procedures in this study were compared to the WHO standards for permissible limits in water and fish (WHO, 2017). Results of the concentration of heavy metals in the water and oyster tissues at the six sites are presented in Figures 25-29. Heavy metal data for March 2022 were excluded due to suspected equipment errors rendering the results either unexplainably high or below detection for all sites.

3.2.2.1 Lead (Pb) concentration in water and oyster tissue

Lead concentration was largely within permissible limits in all waters in all quarters, except Allahein in September and Densu in December. Lead in oyster tissue was above the permissible limit at all sites in 2021.

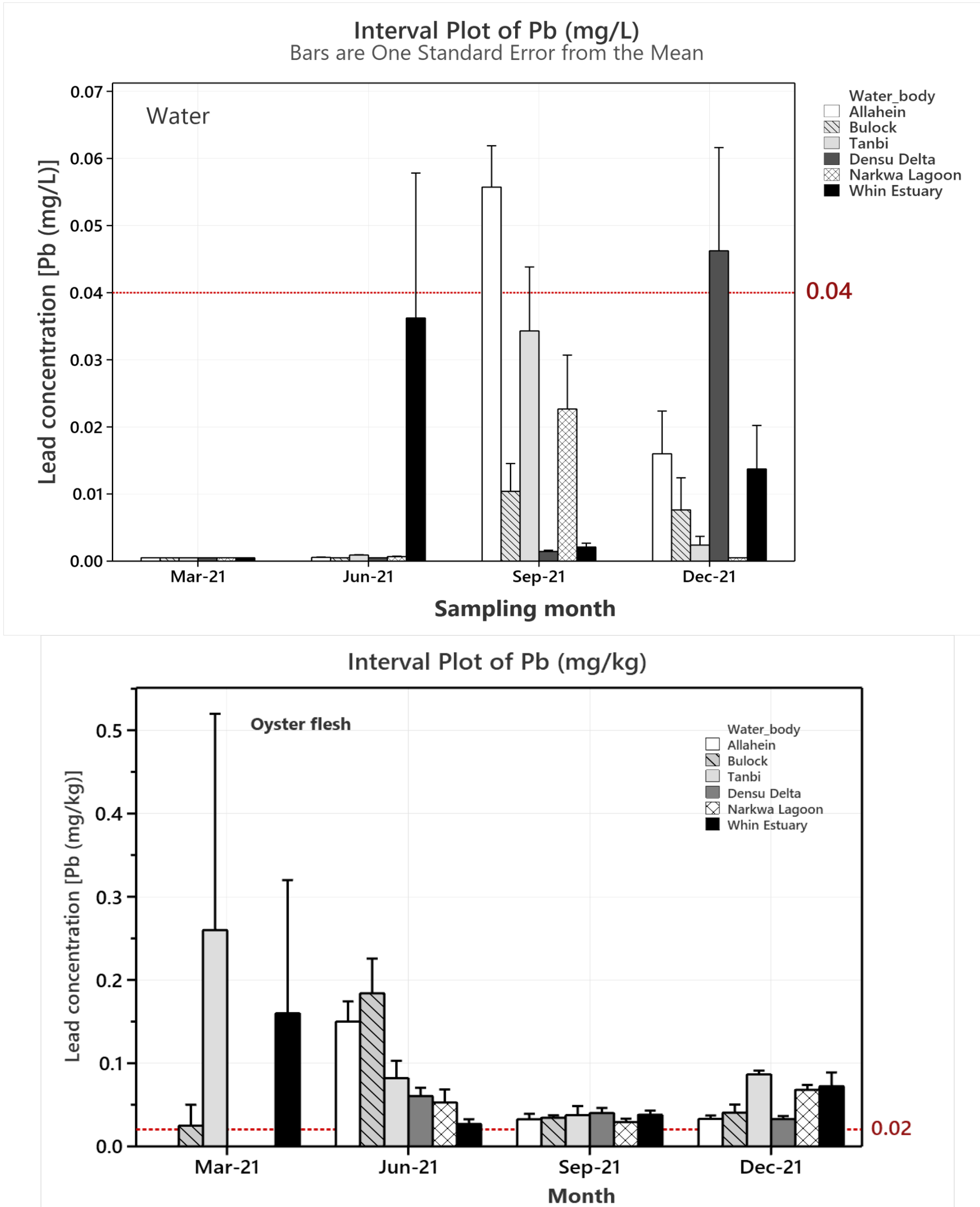
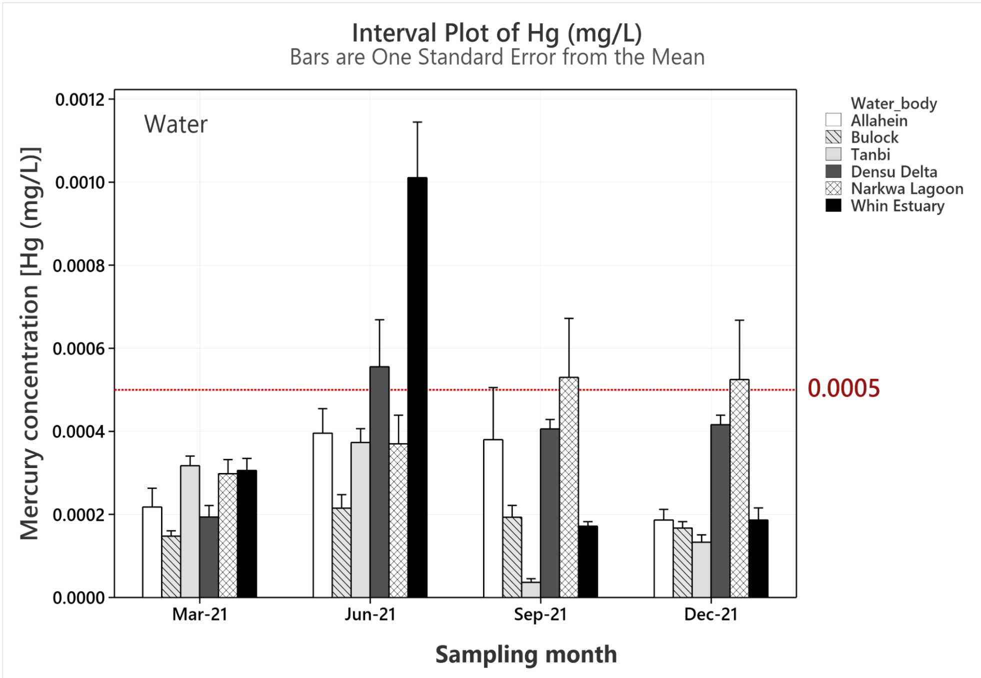


Figure 25: Lead (Pb) concentrations in water samples and oyster tissues at the six sites in Ghana and The Gambia from March 2021 to December 2021.

3.2.2.2 Mercury (Hg) concentration in water and oyster tissue

Mercury was also within the permissible limit in both water and oysters, except in Whin and Densu during June 2021, and in Narkwa in September and December when it was above the WHO limit in the water.



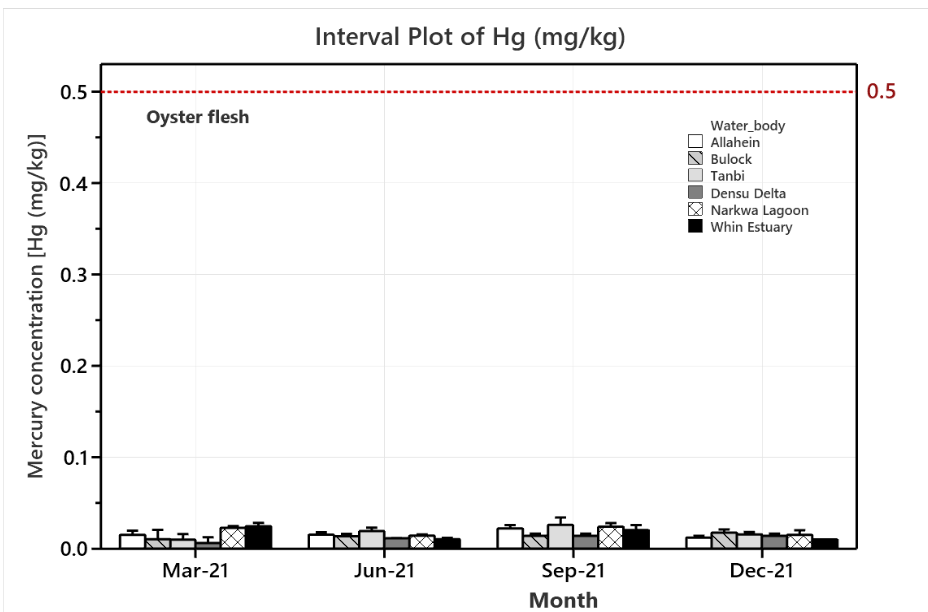
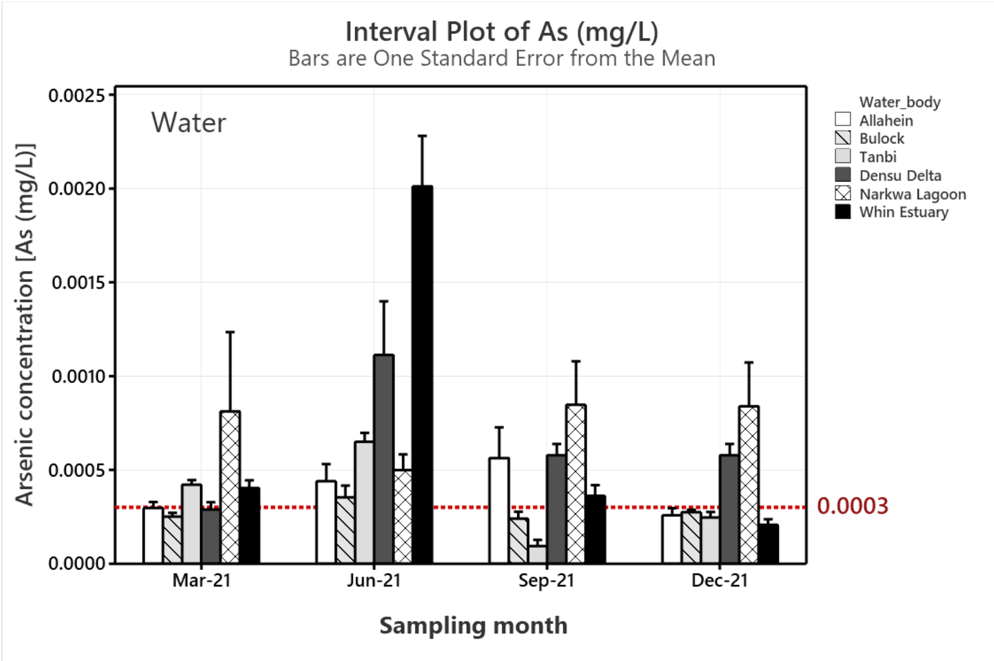


Figure 26: Mercury (Hg) concentrations in water samples and oyster tissues at the six sites in Ghana and The Gambia from March 2021 to December 2021.

3.2.2.3 Arsenic (As) concentration in water and oyster tissue

Arsenic levels in the water were consistently above permissible levels at Narkwa, with all systems above permissible limits in June, especially Densu and Whin. The concentrations were, however, well within permissible levels in the oyster tissue.



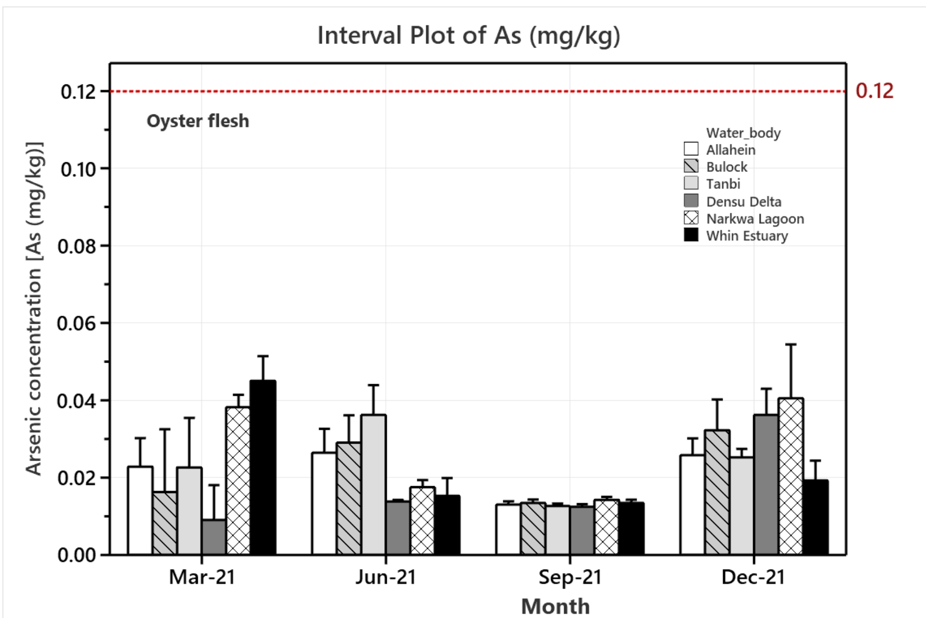


Figure 27: Arsenic (As) concentrations in water samples and oyster tissues at the six sites in Ghana and The Gambia from March 2021 to December 2021.

3.2.2.4 Cadmium (Cd) concentration in water and oyster tissue

Cadmium in waters of all systems was high in March and December 2021 but within permissible limits in June and September 2021. The Cadmium levels in oyster tissue were generally above WHO acceptable limits at most sites in all quarters, showing highly elevated concentrations in all systems in September 2021.

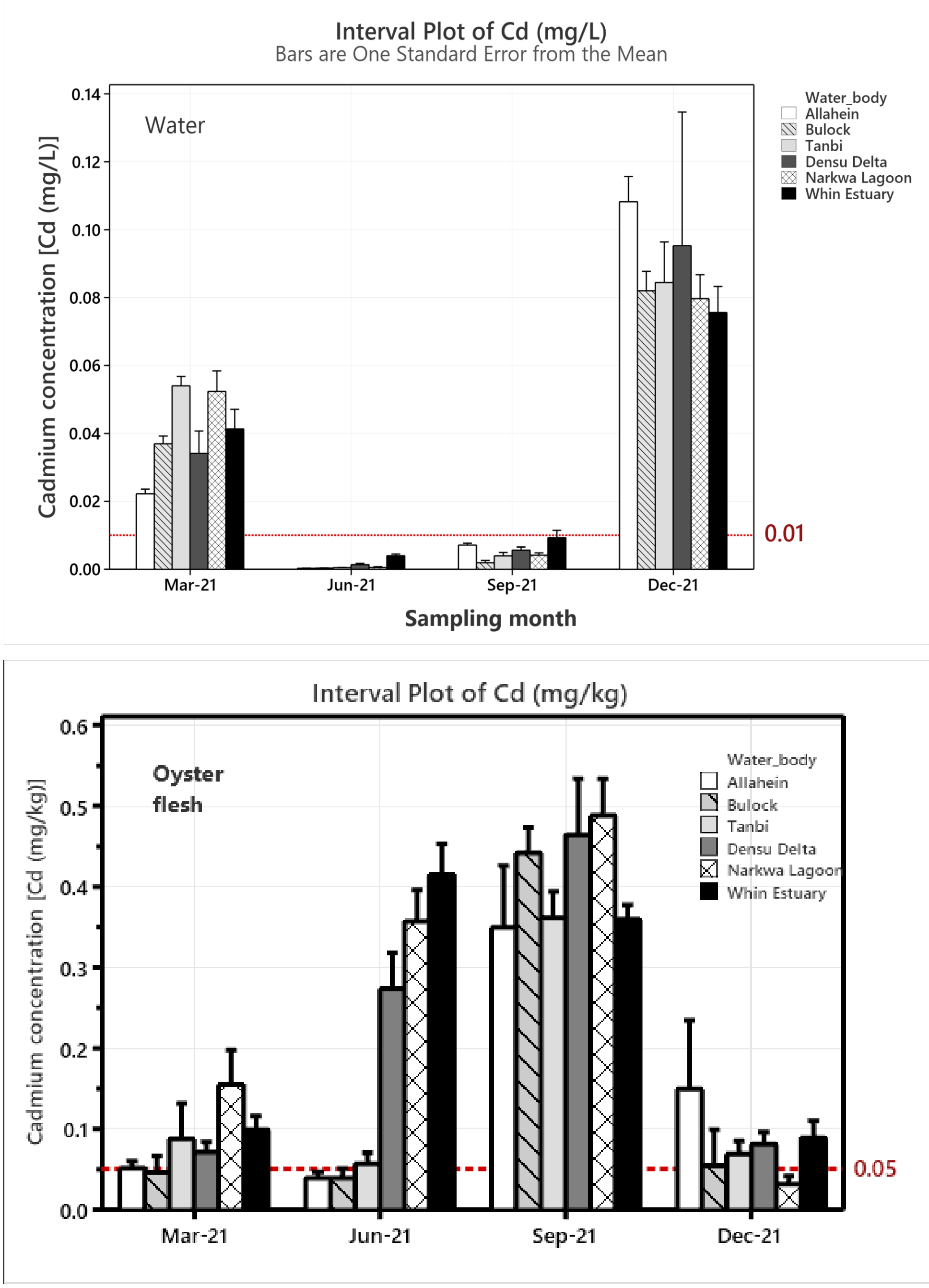
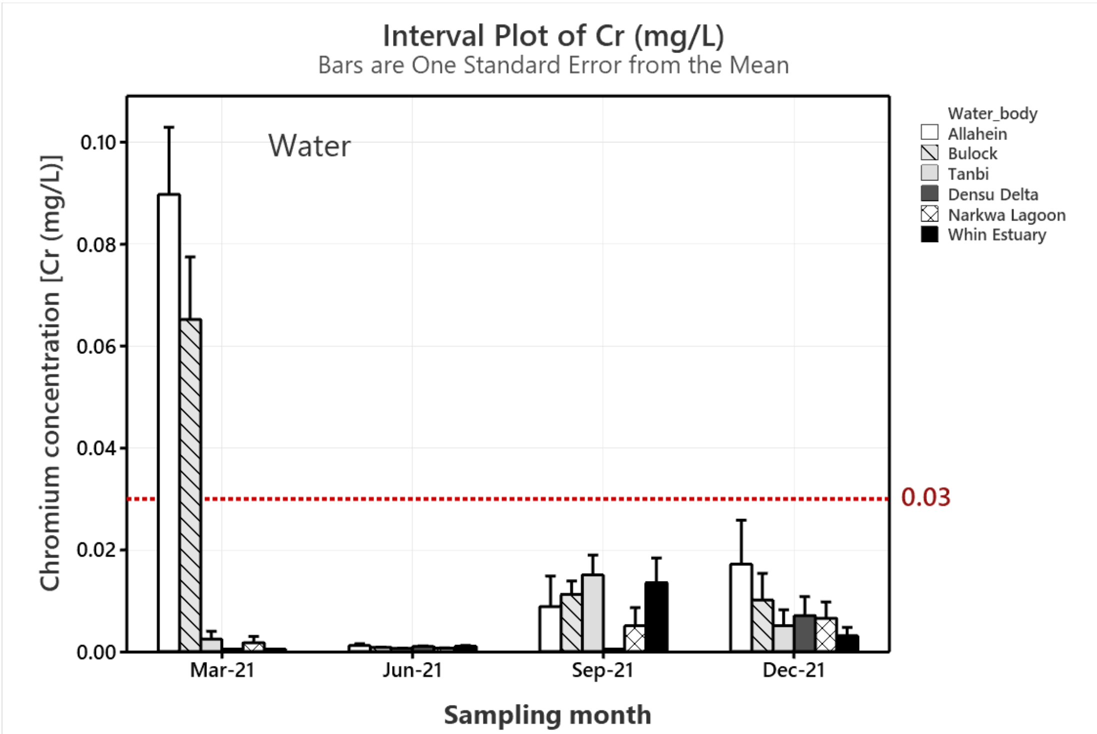


Figure 28: Cadmium (Cd) concentrations in water samples and oyster tissues at the six sites in Ghana and The Gambia from March 2021 to December 2021.

3.2.2.5 Chromium (Cr) concentration in water and oyster tissue

Chromium concentration was generally within permissible limits in all waters in 2021 except in the Allahein and Bulock estuaries where it was high in March 2021. The levels were however within acceptable limits in the oyster tissue, except Whin in March 2021.



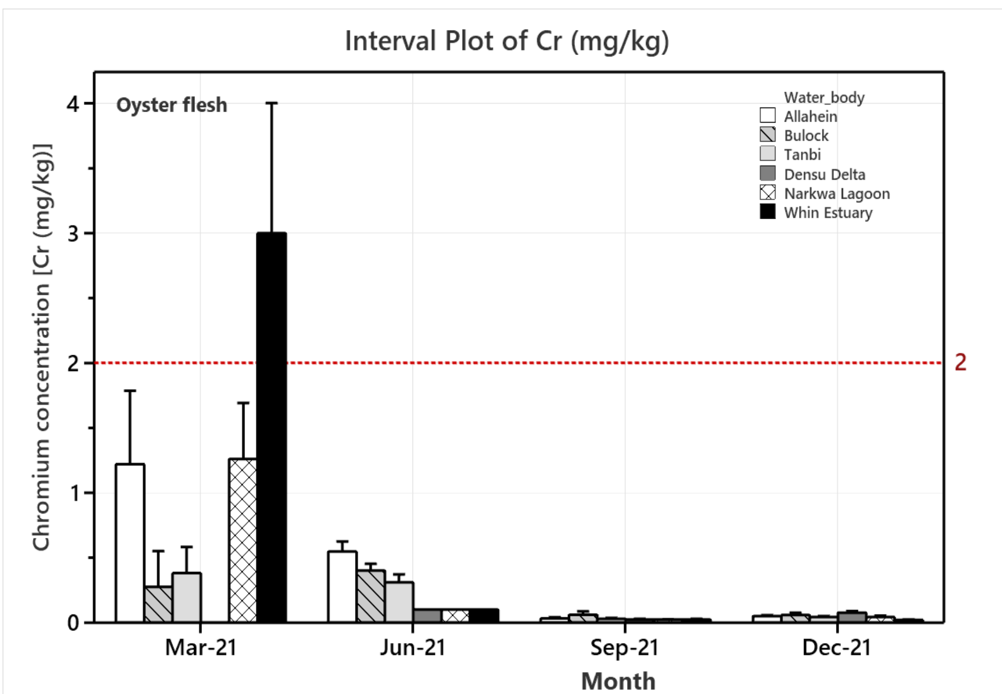


Figure 29: Chromium (Cr) concentrations in water samples and oyster tissues at the six sites in Ghana and The Gambia from March 2021 to December 2021.

3.3 Growth, size structure and reproductive biology of the oyster populations

3.3.1 Sizes and growth

3.3.1.1 Size variations across sites

The overall mean (± SE) shell height (cm) of oysters collected at the sites were Allahein 6.13 (±0.05), Bulock 6.49 (±0.05), Tanbi 6.17 (±0.04), Densu 6.82 (±0.08), Narkwa 4.60 (±0.04) and Whin Estuary 6.10 (±0.06); means were computed from 720 specimens per site. The monthly variation in sizes (mean shell height) of oysters across the sites are shown in Figure 30. Generally, larger mean oyster sizes were encountered between March and May at all the three sites in The Gambia with the largest mean being in Bulock, but the mean sizes dropped significantly in June after which gradual increase in mean size occurred progressively along the year to February 2022 due to growth. In Ghana, oysters appeared to have smaller means between March and May, and larger mean sizes between September and February. In Ghana, Densu had the largest mean size oysters while the smallest mean size oysters were found at Narkwa. Among the six sites, the oysters at Narkwa were consistently the smaller.

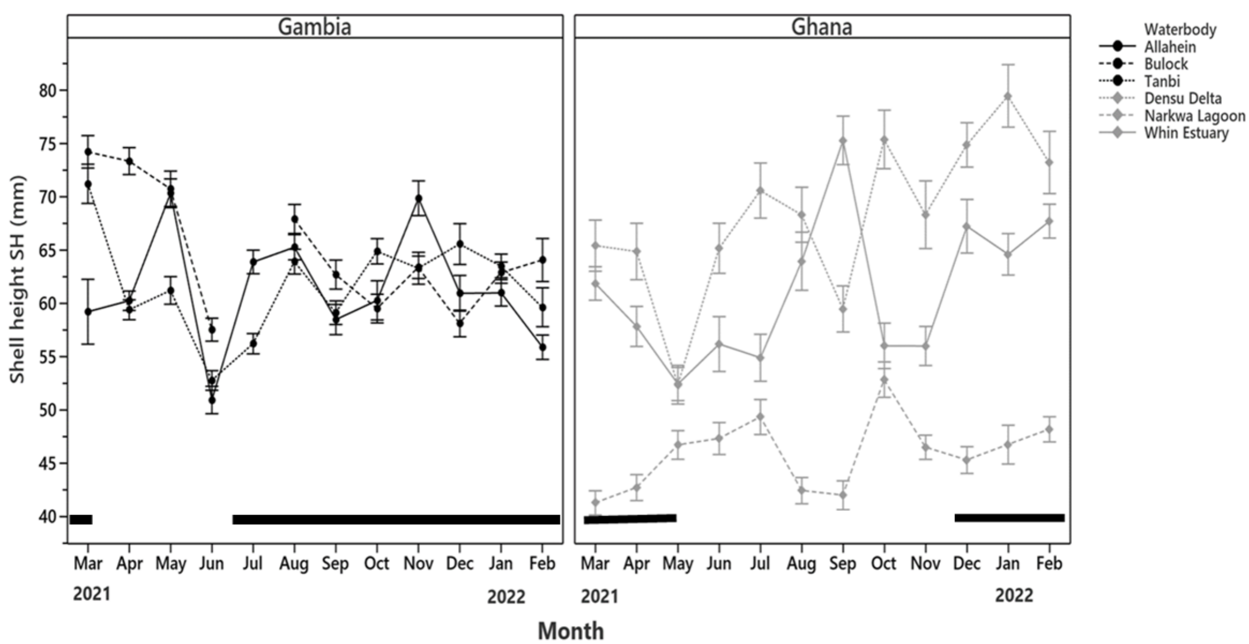


Figure 30: Mean monthly variations in shell height of oysters sampled from the six water bodies in Ghana and The Gambia from March 2021 to February 2022 (black horizontal line represents generic periods of closed season for the Densu in Ghana and all sites in The Gambia.

3.3.1.2 Size-frequency distribution

As shown in Figure 31, all the oyster populations showed a unimodal distribution of shell height (SH). The Gambia populations as well as the Densu population showed larger modal sizes around 6 cm

SH, while Whin and Narkwa had smaller modal sizes at around 4 cm SH. Narkwa had the smallest modal sizes.

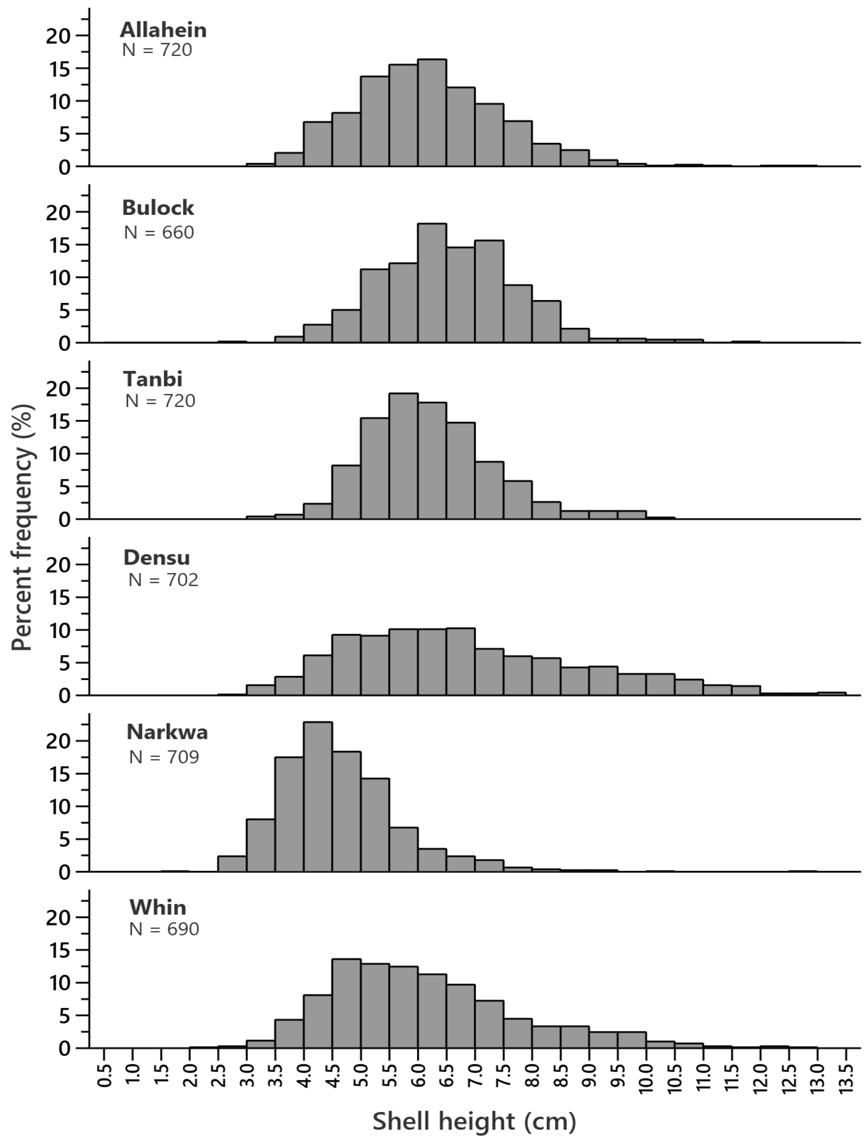


Figure 31: Size distribution of mangrove oysters (Crassostrea tulipa) sampled monthly from the six water bodies in Ghana and The Gambia from March 2021 to March 2022.

3.3.2 Condition Index

While the Condition Index of the oyster populations in The Gambian waters showed one peak period (March-May) over the one year study period, the populations in the Ghanaian systems showed at least two peak periods, with the first high condition occurring in June-September, and the second in December-January (Figure 32). The Ghana populations experienced lowest condition in March-April and October 2021, while The Gambia populations were of lowest condition in October-November 2021.

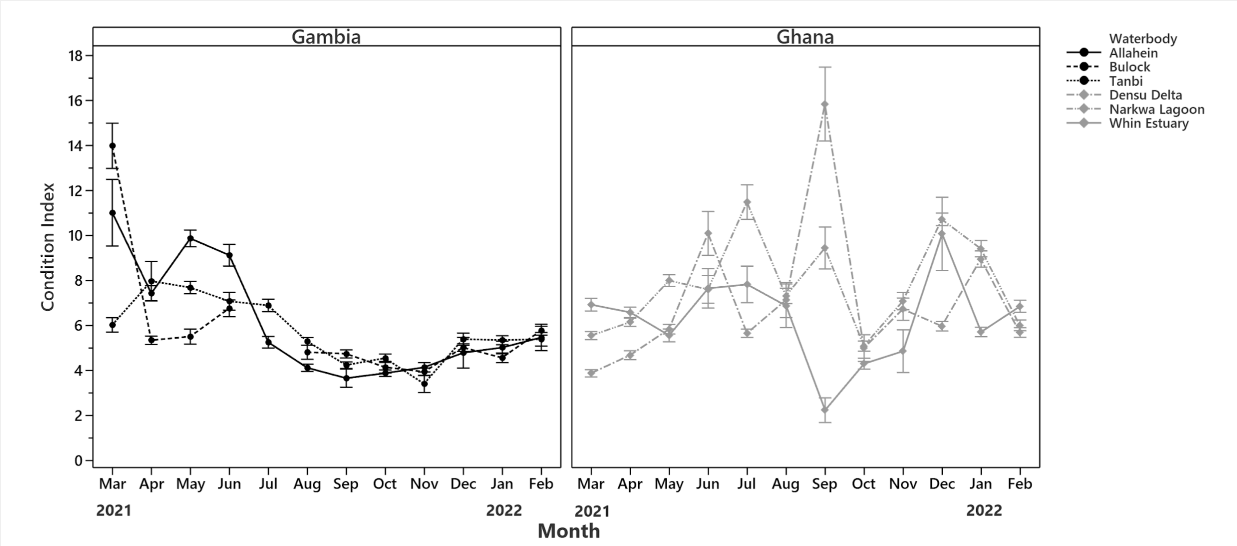


Figure 32: Mean monthly variations in Condition Index of oysters sampled from the six water bodies in in Ghana and The Gambia from March 2021 to March 2022.

3.4 Maturity, sex ratio and reproduction of the oyster populations

3.4.1 Maturity sizes

The smallest mature oysters encountered at all the six sites are presented in Table 3. The smallest mature male and female specimens in each waterbody were of the same size. The sizes however differed across sites, with the largest recorded at Bulock, followed by Allahein and Whin, then Tanbi, Densu, and Narkwa, in that order.

Figure 33 shows the cumulative frequency of length at maturity and length at Lm_{50}. This analyses of maturity sizes (Lm_{50}) of the populations (the size at which 50 percent of the population is mature) again showed that the Bulock oysters had the largest maturity size (5.6 cm), followed by Densu (5.4 cm), Allahein (5.3cm), Tanbi (5.2 cm), Whin (4.9 cm), and the smallest in Narkwa (3.6 cm).

Table 3: Sizes of smallest mature oysters encountered at each of the six study sites.

Site	Smallest mature specimen [SH (cm)]		Lm_{50} [SH (cm)]
	Male	Female	
Densu	3.0	3.0	5.4 cm
Narkwa	2.6	2.6	3.6 cm
Whin	3.4	3.4	4.9 cm
Allahein	3.4	3.4	5.3 cm
Bulock	3.6	3.6	5.6 cm
Tanbi	3.2	3.2	5.2 cm

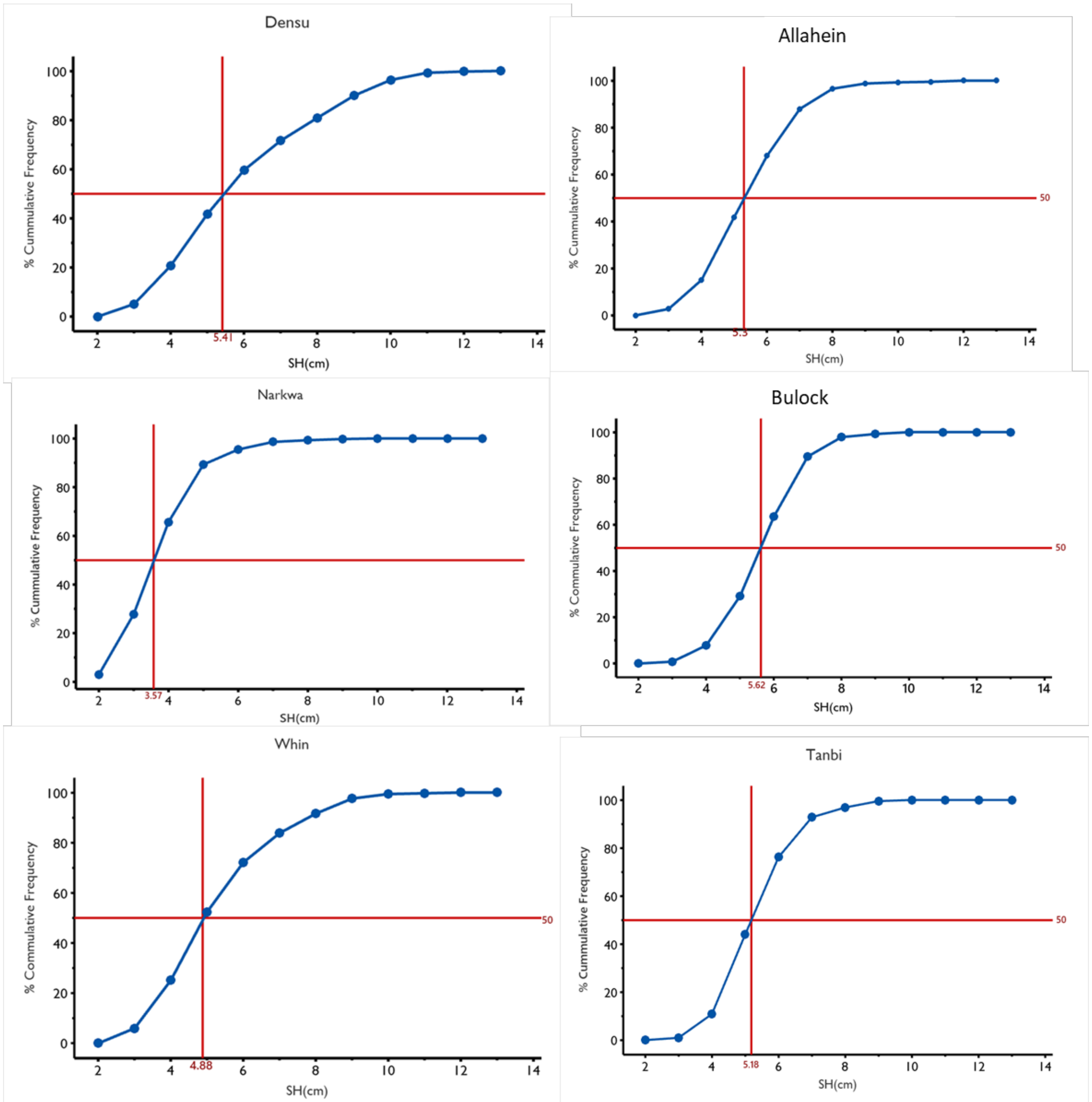


Figure 33: Maturity size of the mangrove oysters (Crassostrea tulipa) sampled from the six water bodies in Ghana and The Gambia.

3.4.2 Sex ratios

From the monthly sex ratios (Figure 34), there seems to be preponderance of female oysters at Bulock and Tanbi, and male oysters at Densu. Other sites such as Narkwa showed a gradual shift from higher numbers of males in March-April towards dominance of females in November-December, and then female dominance in January-February. The highest proportion of individuals of indeterminate sex were recorded in March 2021 at the sites in The Gambia while the populations in Ghana had most of these between July and September.

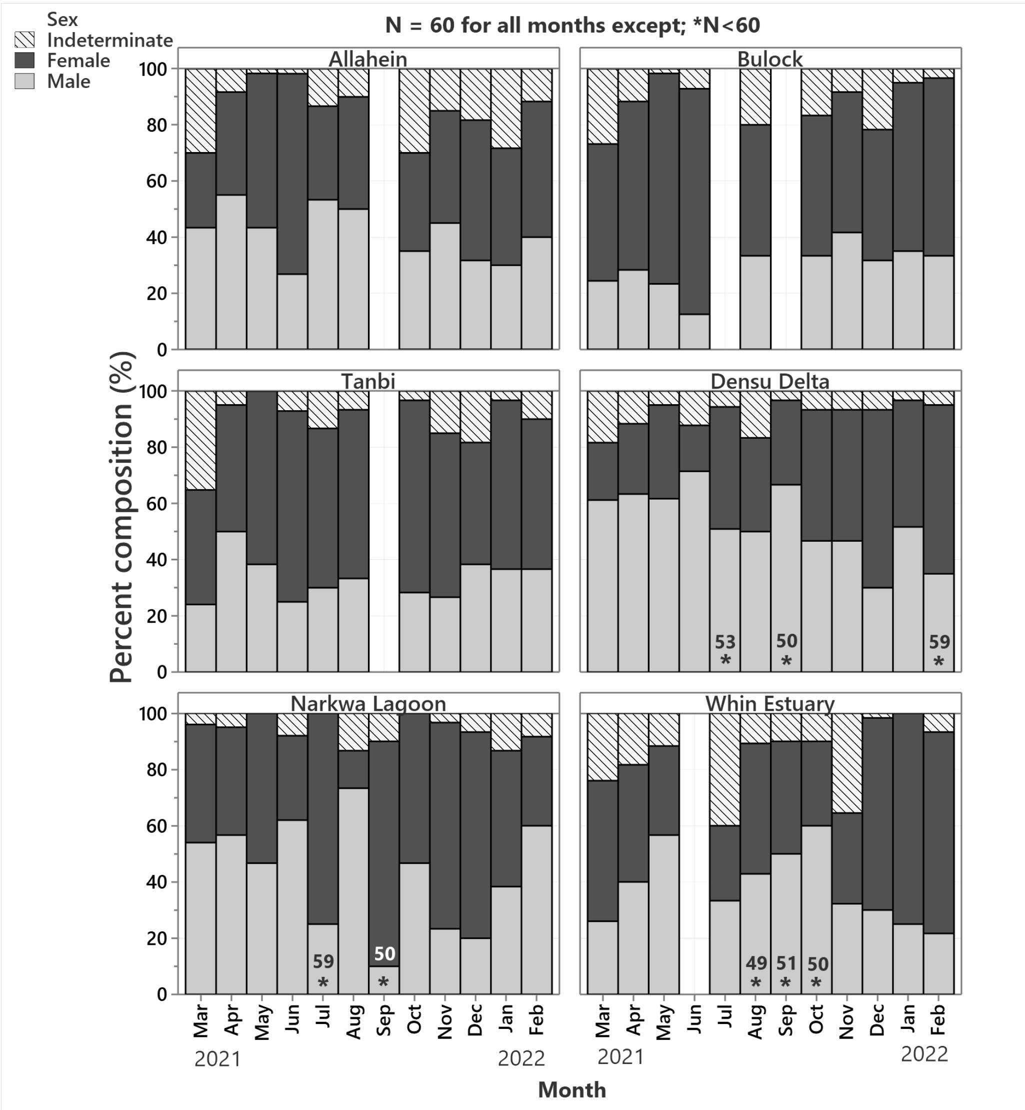


Figure 34: Percentage composition of the sex ratios for mangrove oysters (Crassostrea tulipa) sampled from the six water bodies in The Gambia and Ghana from March- December 2021.

3.4.3 Gonadal development and maturation

Photomicrographs of five gametogenic stages of male and female *C. tulipa* from the selected oyster sites in Ghana and The Gambia are illustrated in Figure 35 as developing, ripening, ripe, spawning and resorption/redevelopment (Marroquin-Mora and Rice, 2008). The letter "*a*" represents the female developmental stages, whereas "*b*" is that of males.

Stage 1: *Developing* - Primary oocytes and primary spermatocytes are typically found in the female follicle at this stage as seen in Figure 35 (1a), while the male follicle at this stage contains mainly primary spermatocytes (Figure 35 (1b).

Stage 2: Ripening - Stage 2 female and male oysters show comparatively larger follicles as compared to Stage 1 specimens. Sex cells within follicles are typically oocytes in females (Figure 6: 2a) whereas the males have spermatocytes and spermatozoa (Figure 35 (2b)). Oocytes are tightly packed and separated from the follicular walls, while the spermatozoa are few and confined to the lumen of the follicles.

Stage 3: Ripe - Oysters at this gametogenic stage have gonads fully occupied with expanded follicles. The gonadal connective tissues in both sexes are completely displaced. Female and male follicles contain primarily loose mature ova (Figure 35 (3a)) and well-packed spermatozoa with tails toward the lumen of the follicle (Figure 35 (3b)), respectively. Walls of the follicles are intact in both sexes.

Stage 4: Spawning - Stage 4 female and male oysters have released gametes and the follicles appear partially emptied as seen in Figure 35 (4a and 4b). Follicular walls are thin and broken.

Stage 5: Resorption/redevelopment - Stage 5 oysters have empty shrunken follicles as a result of spawning with a few dispersed remnant gametes. These follicles are seen to be undergoing resorption of relic sex cells or redevelopment of oocytes (Figure 35 (5a)) and spermatocytes (Figure 35 (5b)).

Hermaphroditic oyster specimen - shows a functional gametogenic activity with female gametes at the ripening stage, whereas the male gametes are undergoing resorption and redevelopment Figure 35 (6).

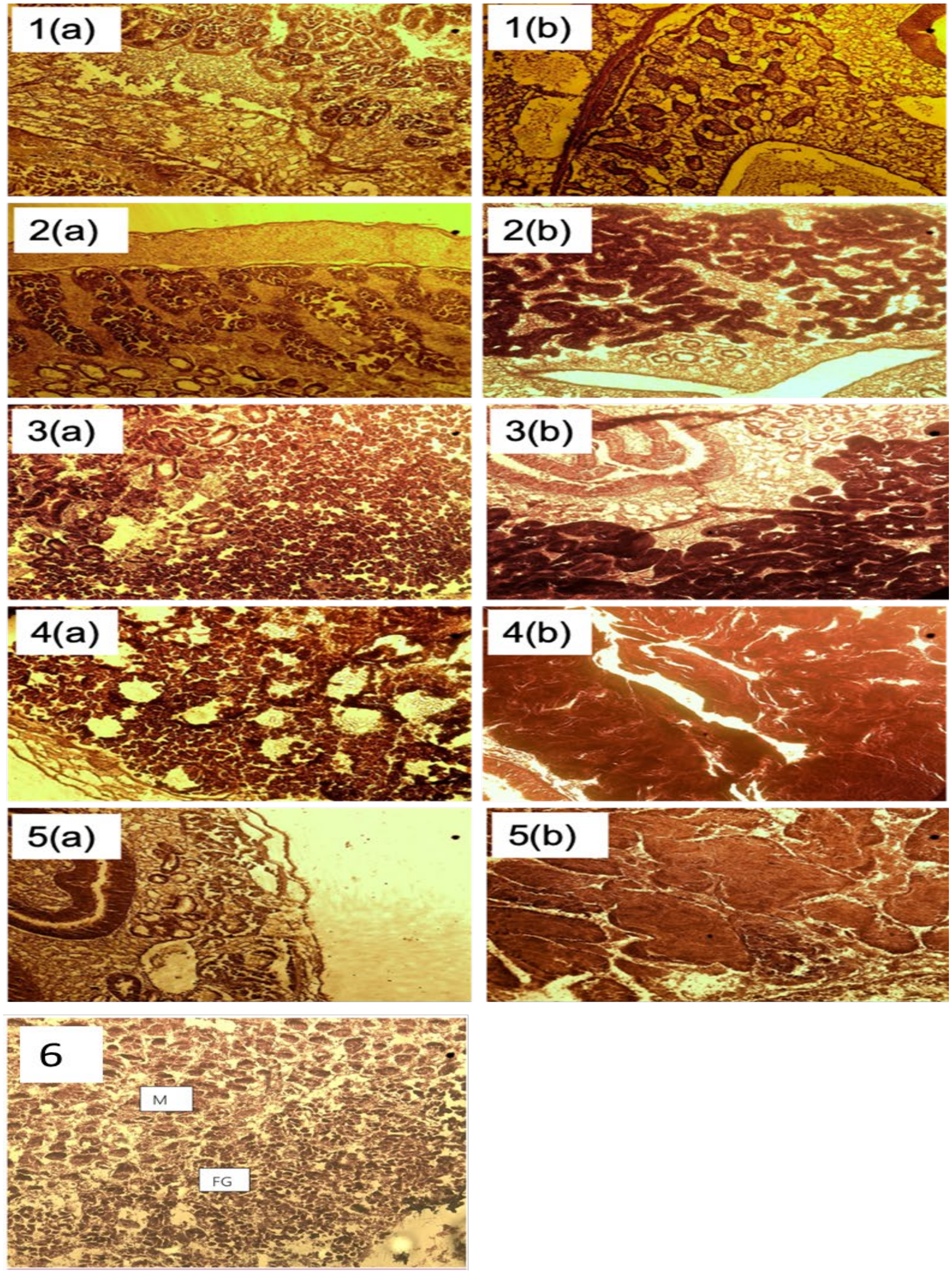


Figure 35: Photomicrographs of gametogenic stages of Crassostrea tulipa: developing - (1a) female, (1b) male; ripening - (2a) female, (2b) male; ripe - (3a) female, (3b) male; spawning - (4a) female, (4b) male; resorption/re development - (5a) female, (5b) male. hermaphrodite (6).

Generally, the gonad index was highest for all populations in March 2021, dropping steeply for the Gambia population in June, and progressively for the Ghana oysters until the periods of September-December 2021 (Figure 36). Minor peaks were observed for the Bulock and Tanbi oysters in September, and the Whin oysters in December 2021. Approximately five percent and 16 percent of the 500 and 600 examined specimens in Ghana and The Gambia respectively, were hermaphrodites.

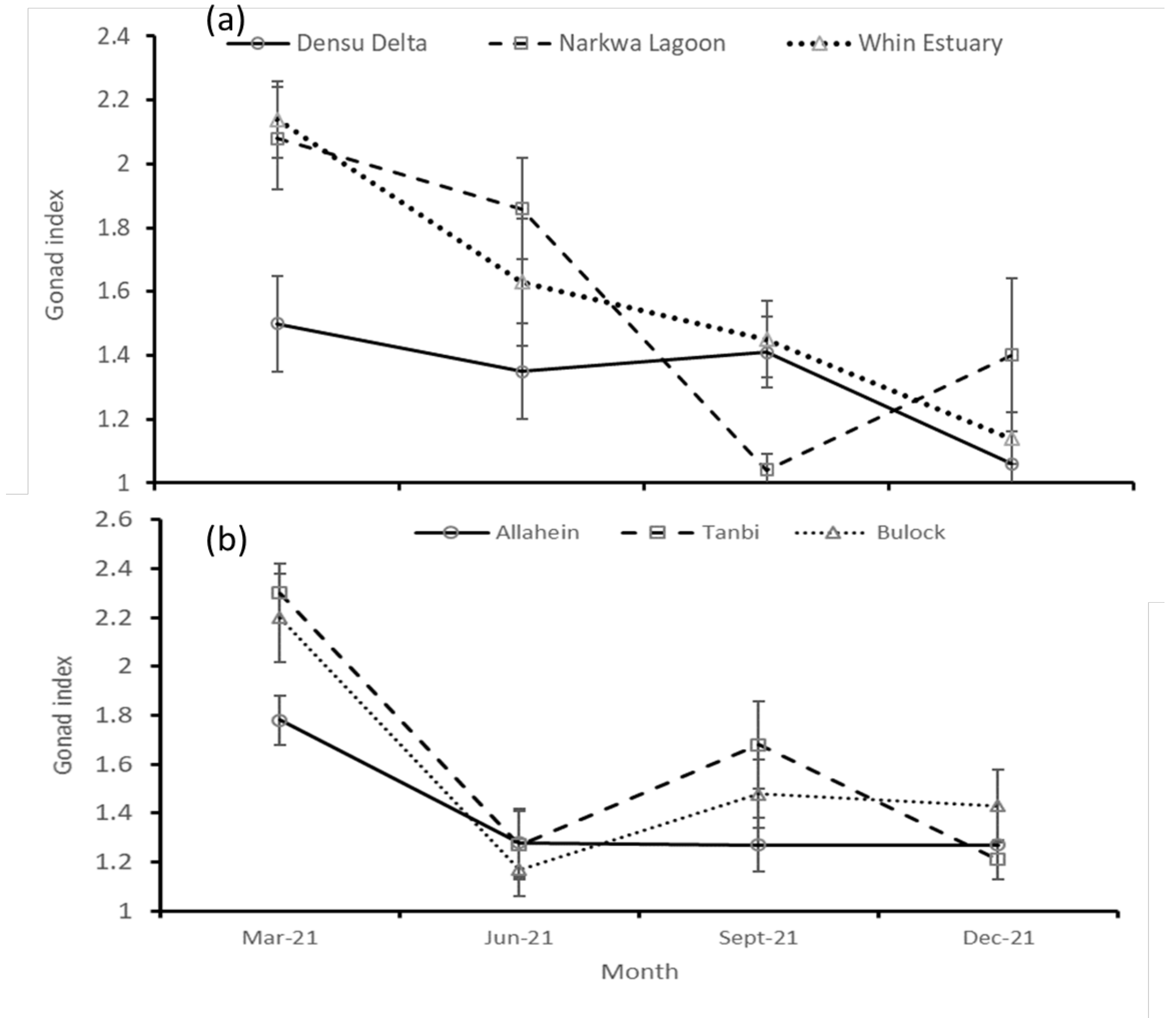


Figure 36: Mean quarterly variations of gonad indices of Crassostrea tulipa in the six systems in (a) Ghana and (b) The Gambia (vertical bars indicate standard errors).

3.5 The oyster fisheries and sustainability

3.5.1 Growth and mortality of the oyster populations

The monthly length-frequency distributions of the oysters from each of the six sites fitted with the von Bertalanffy growth curve using the TropFishR package are presented Figures 37 and 38. The distributions show the occurrence of smaller oysters around 4 cm SH constituting the modal sizes in certain months of the year in Allahein (March and June), Bulock (June), Tanbi (April-July but significantly June), Densu (May), Narkwa (March-May), Whin (May-July). These importantly point to the first half of the year as the possible major spawning period of the species in all the six systems, with intensity of spawning varying among the sites.

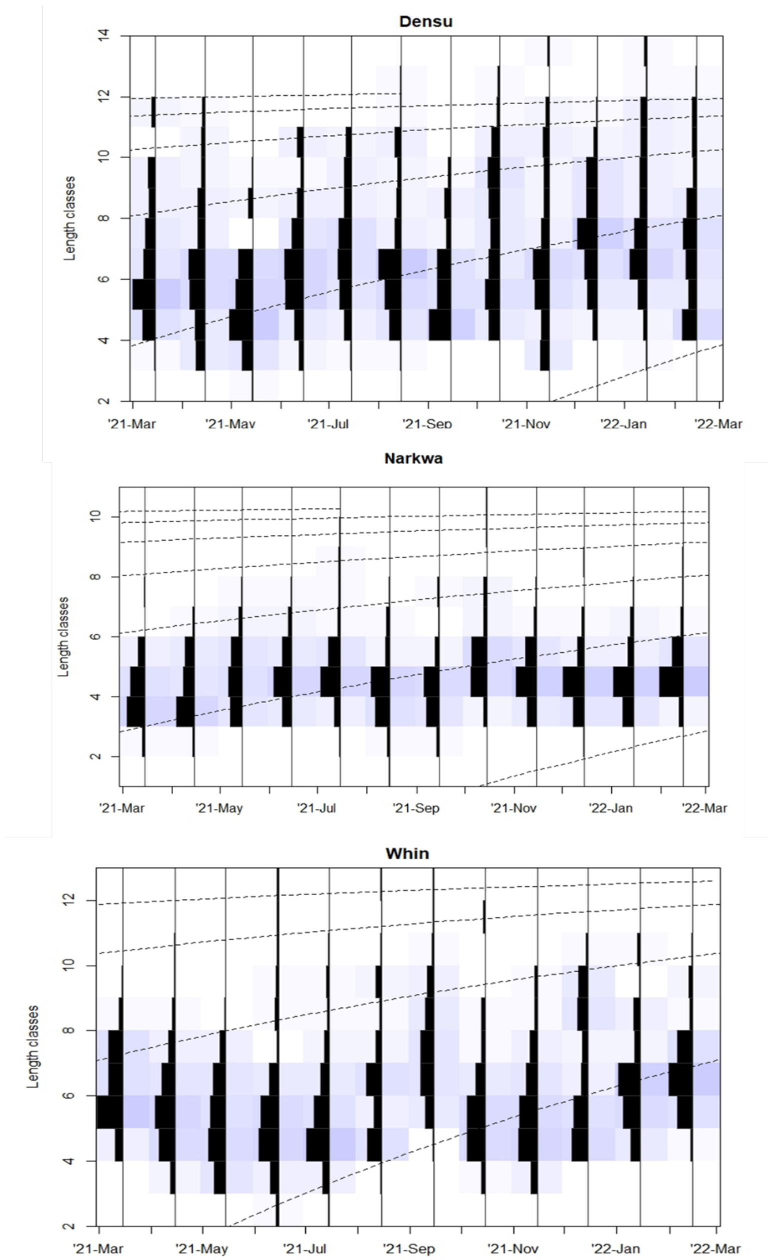


Figure 37: Monthly length-frequency distribution of the oysters sampled from the three water bodies in Ghana fitted with the Von Bertalanffy growth curve.

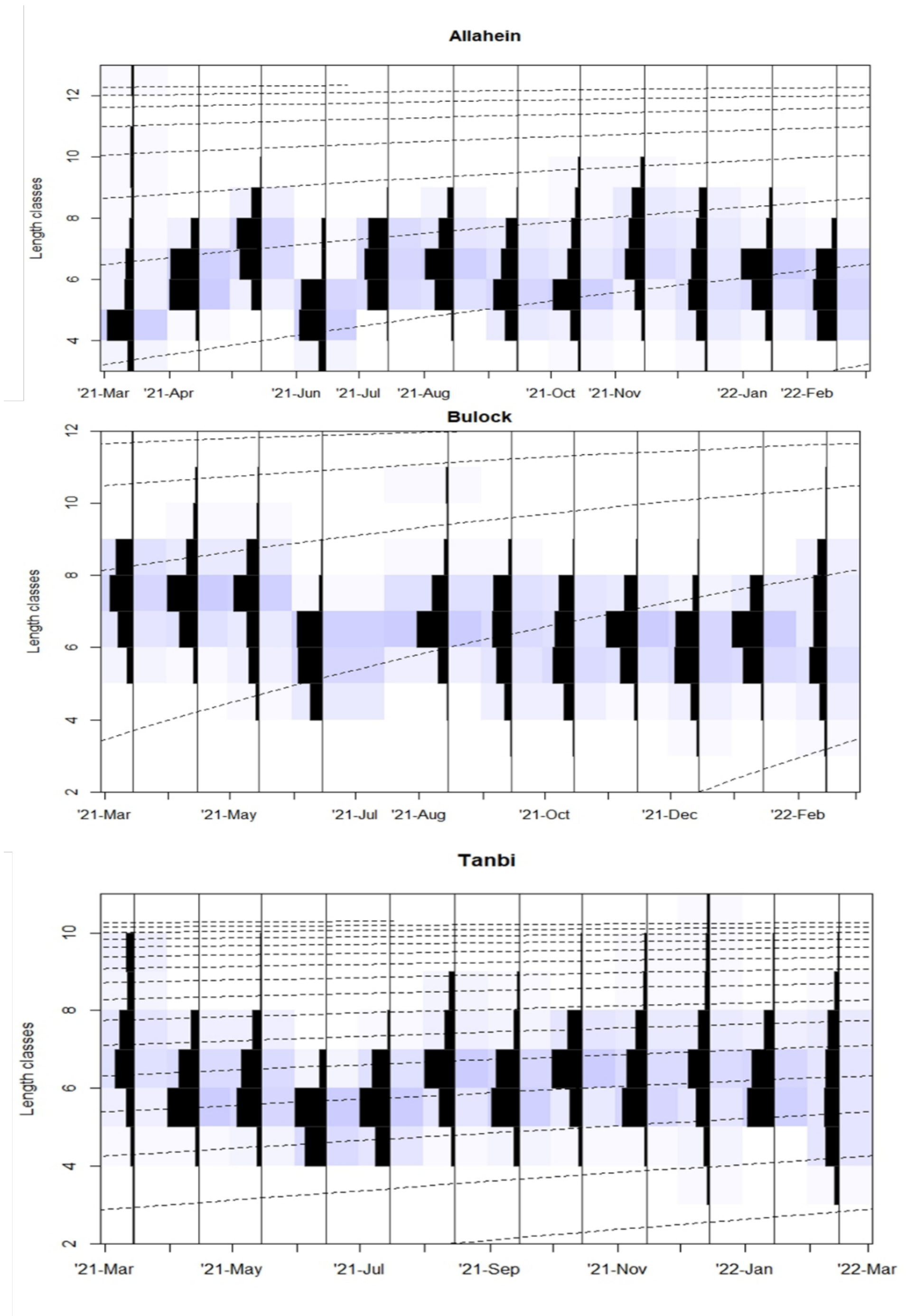


Figure 38: Monthly length-frequency distribution of the oysters sampled from the three water bodies in The Gambia fitted with the Von Bertalanffy growth curve.

The yearly plot of the von Bertalanffy growth curve with growth parameters estimated (with 95 percent confidence interval) using the ELEFAN_GA (Electronic LEngth Frequency ANalysis with genetic algorithm) package of TropFishR are also presented in Figure 39 and 40. Overall, the population with the largest maximum theoretical size was the Whin oysters (L_∞ = 13.2 cm SH), with the Narkwa population having the smallest (L_∞ = 10.72 cm SH). Oysters in the Gambia had L_∞ varying from 12.9 cm (Bulock) to 10.8 (Tanbi).

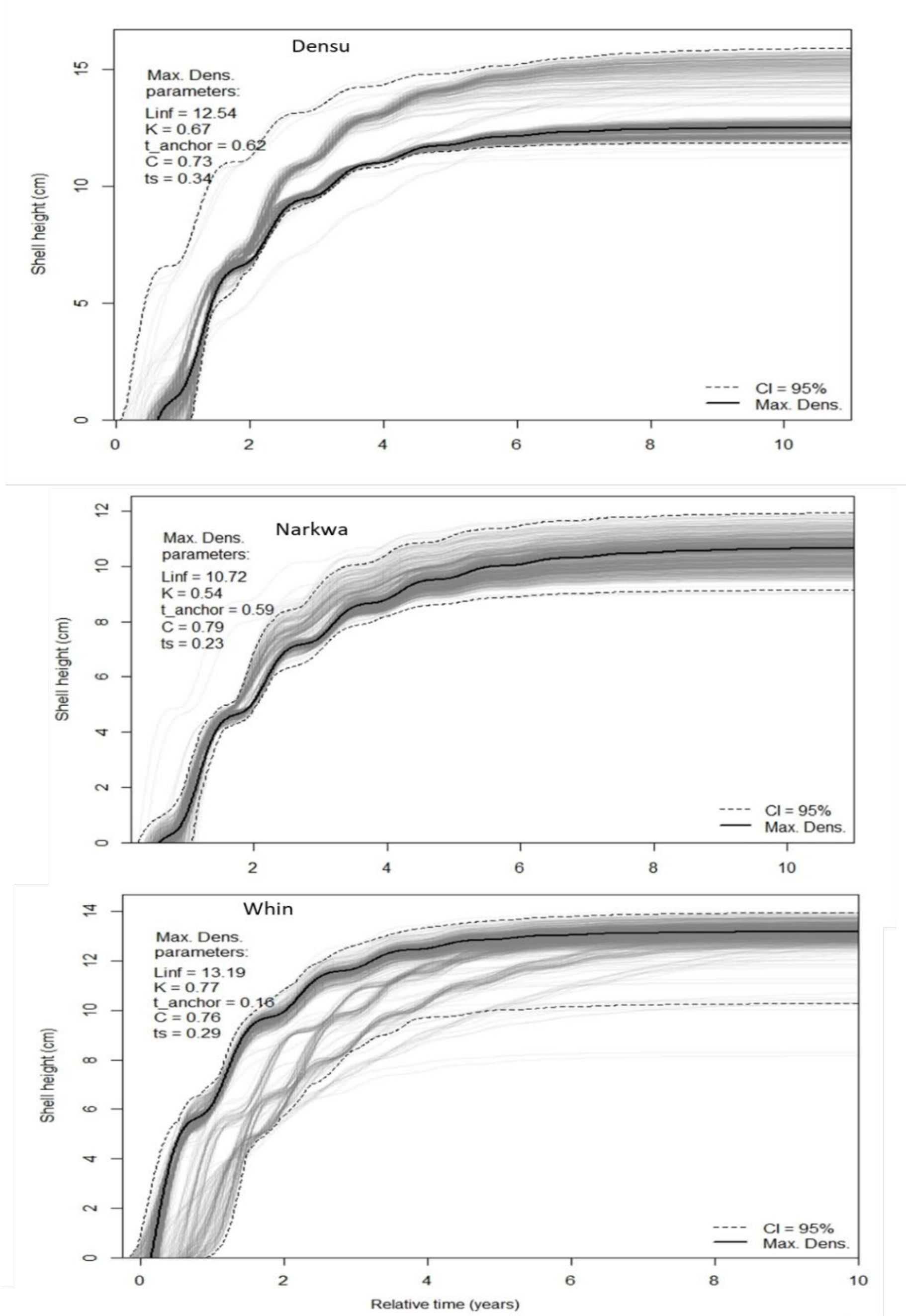


Figure 39: Von Bertalanffy growth curve of the mangrove oysters (Crassostrea tulipa) sampled from the three water bodies in Ghana with 95 percent confidence interval.

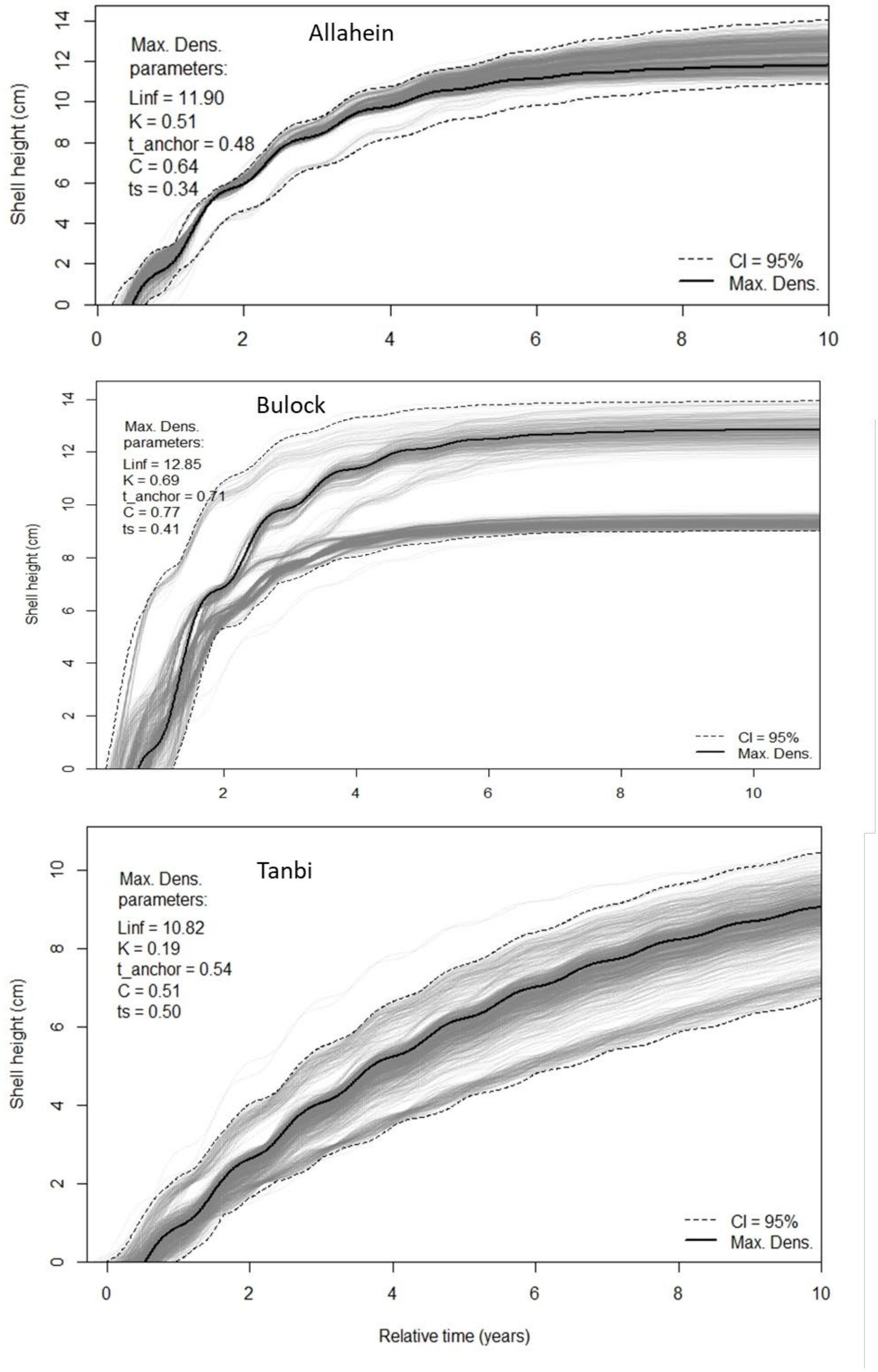


Figure 40: Von Bertalanffy growth curve of the mangrove oysters (Crassostrea tulipa) sampled from the three water bodies in The Gambia with 95 percent confidence interval.

Results of total mortality estimates for the oyster stocks in Ghana (Figure 41) and The Gambia (Figure 42) are provided below.

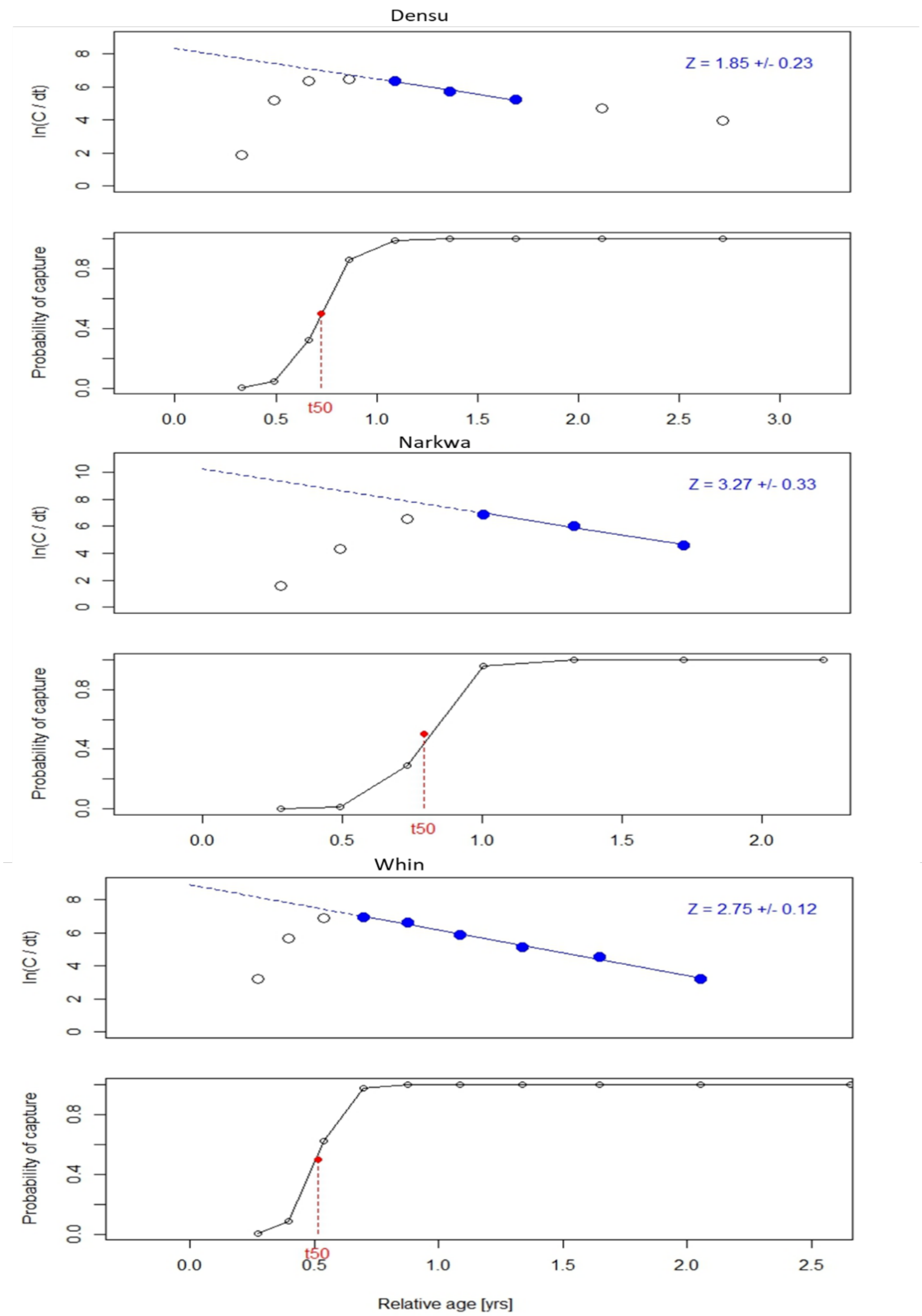


Figure 41: Catch-curve distribution and probability of capture of the mangrove oysters (Crassostrea tulipa) from the three water bodies in Ghana..

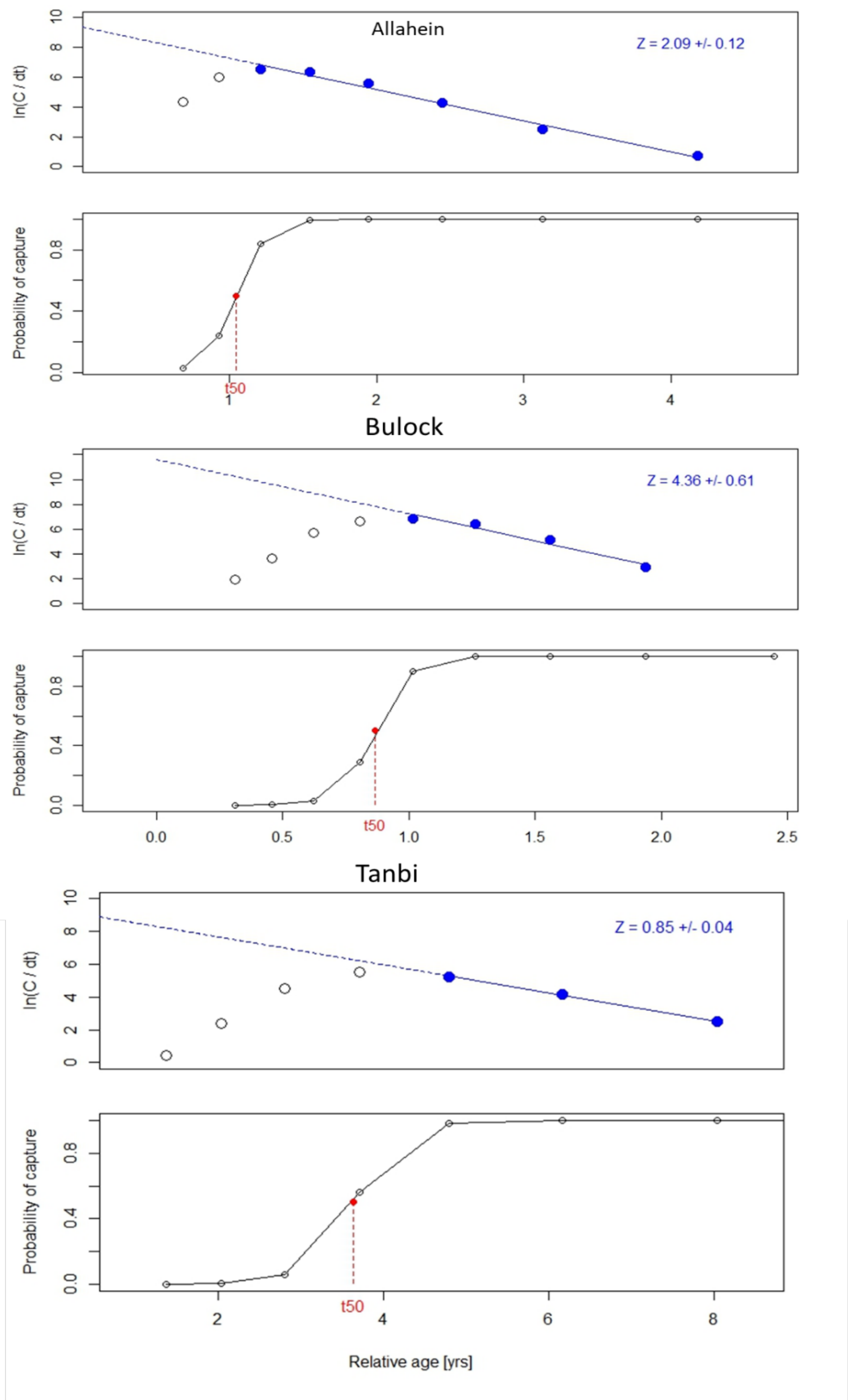


Figure 42: Catch-Curve distribution and Probability of Capture of the mangrove oysters (Crassostrea tulipa) sampled from the three water bodies in The Gambia.

3.5.2 Exploitation of the oyster stocks

Detailed comparison and summary interpretation of the growth, mortality and exploitation parameters estimated for the oyster stocks across the six sites are presented in Table 4. Under optimum exploitation conditions for a fishery (Gulland, 1977; Pauly, 1980b), the fishing mortality (F) is expected to constitute between one-third and half of the total mortality (Z). The sustainable exploitation ratio (E = F/Z) range for exploited fish species is therefore 0.3 – 0.5. Values beyond 0.5 indicate that the stock is overexploited. Analyses of the exploitation ratio computed with data from the growth and mortality parameters for the data of March 2021 to February 2022 show that the Densu and Tanbi oyster stocks are underexploited, whereas Whin and Allahein are optimally exploited, while Narkwa and Bulock stocks are overexploited (Table 4). It is important to indicate that size-structured models with monthly size data inputs were used in estimating the exploitation parameters and that closed seasons were implemented for prolonged periods at Densu and The Gambian sites during the study period. This possibly influenced the outputs on fishing mortality as there was no fishing for most months, hence the consequently low exploitation ratio values.

Table 4: A comparative summary of the growth parameters, mortality rates, and exploitation indices of the oyster stocks from the six waterbodies in The Gambia and Ghana.

Site	Growth Parameters			Mortality Parameters			Exploitation Indices		
	L_∞	K	t_{anchor}	M	Z	F	E	L_c/L_{50}	Interpretation
Densu	12.5	0.67	0.62	1.78	1.85	0.07	0.04	4.8	Stock is under-exploited; oysters of shell height 4.8 cm have 50 percent probability of being harvested
Narkwa	10.7	0.54	0.59	1.62	3.27	1.65	0.51	3.7	Stock is over-exploited; oysters of shell height 3.7 cm have 50 percent probability of being harvested
Whin	13.2	0.77	0.16	1.95	2.75	0.80	0.29	4.3	Optimally exploited; oysters of shell height 4.3 cm have 50 percent probability of being harvested
Allahein	11.9	0.51	0.48	1.50	2.09	0.59	0.28	4.9	Optimally exploited; oysters of shell height 4.9 cm have 50 percent probability of being harvested
Bulock	12.6	0.69	0.71	1.80	4.36	2.56	0.59	5.8	Oyster stock is over-exploited; oysters of shell height 5.8 cm have 50 percent probability of being harvested
Tanbi	10.8	0.19	0.54	0.81	0.85	0.04	0.05	5.4	Stock is under-exploited; oysters of shell height 5.4 cm have 50 percent probability of being harvested

Note: *L_∞ (cm) = maximum theoretical size; K (year^{-1})= growth constant; t_{anchor} = time/period of the year for birth/recruitment into the population (June =0.5, December =1); M(year^{-1})= natural mortality; Z(year^{-1}) = total mortality; F(year^{-1}) = fishing mortality; E = exploitation ratio; L_c/L_{50}= length at which there is 50 percent probability that the oyster will be harvested/captured.*

3.5.3 Trends of Catch Per Unit Effort (CPUE)

As explained earlier in Section 2.2.12, catch and effort data were collected for only Tanbi and Bulock in The Gambia in 2021, and data could not be collected for Allahein due to the fact that the fishery was closed for the whole of 2021. Data collection at all sites in Ghana commenced in 2022, and for

Densu where the fishery was closed in 2021 and opened in April 2022, data was collected only for May 2022 prior to the compilation of this report. Even for Tanbi and Bulock, the very short nature of the season when open, makes it difficult to follow any significant trends of CPUE. The CPUE, estimated as catch per shellfisher per hour from an average of six fishing hours per day, was generally between 10kg and 15 kg per person per hour at The Gambian sites (both Tanbi and Bulock) during March to June 2021 when the season was open but quadrupled to over 40kg per person per hour in Tanbi during the peak of the harvesting season in April 2021. The CPUE at Densu and Whin hovered within the same range between 15kg and 20kg per shellfisher per day over the months, but the harvests for the Narkwa women dropped from around 15 kg per shellfisher per hour at the beginning of the harvest season in February 2022, to much lower quantities (about 5-7kg per shellfisher per hour) through March to May 2022 (Figure 43).

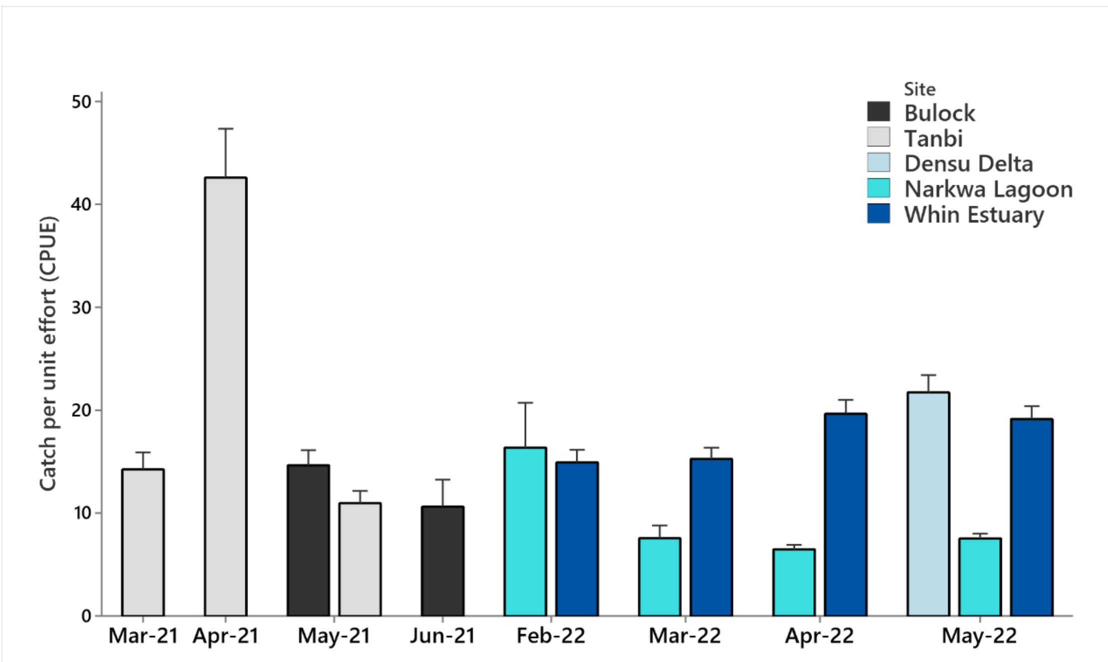


Figure 43: Catch per Unit Effort of the mangrove oyster (Crassostrea tulipa) fishery harvested from the study sites between March 2021 and May 2022.

3.5.4 Harvesting Intensity at the six sites

The extent of mangrove cover at each site, the respective shellfishing areas are shown in Figure 44. Total shellfishing area assumes the area covering the entire water, in addition to a 2 m buffer into mangrove swamps where present. The 2 m buffer was deduced from several in-situ measurements of mangrove areas adjacent to water that are usually accessible for shellfishing and have shellfish, mainly oysters. Some sections may have a wider buffer based on the geomorphology as well as creeks that enable shellfishers to harvest from deeper areas of the mangrove swamps, and it is assumed that these areas are compensated for by the inclusion of the adjacent water area. Comparatively, Tanbi has the largest shellfishing area, followed by Bulock and Allahein among the Gambian sites, and then Densu as the largest in Ghana, followed by Whin, with Narkwa having smallest shellfishing area.

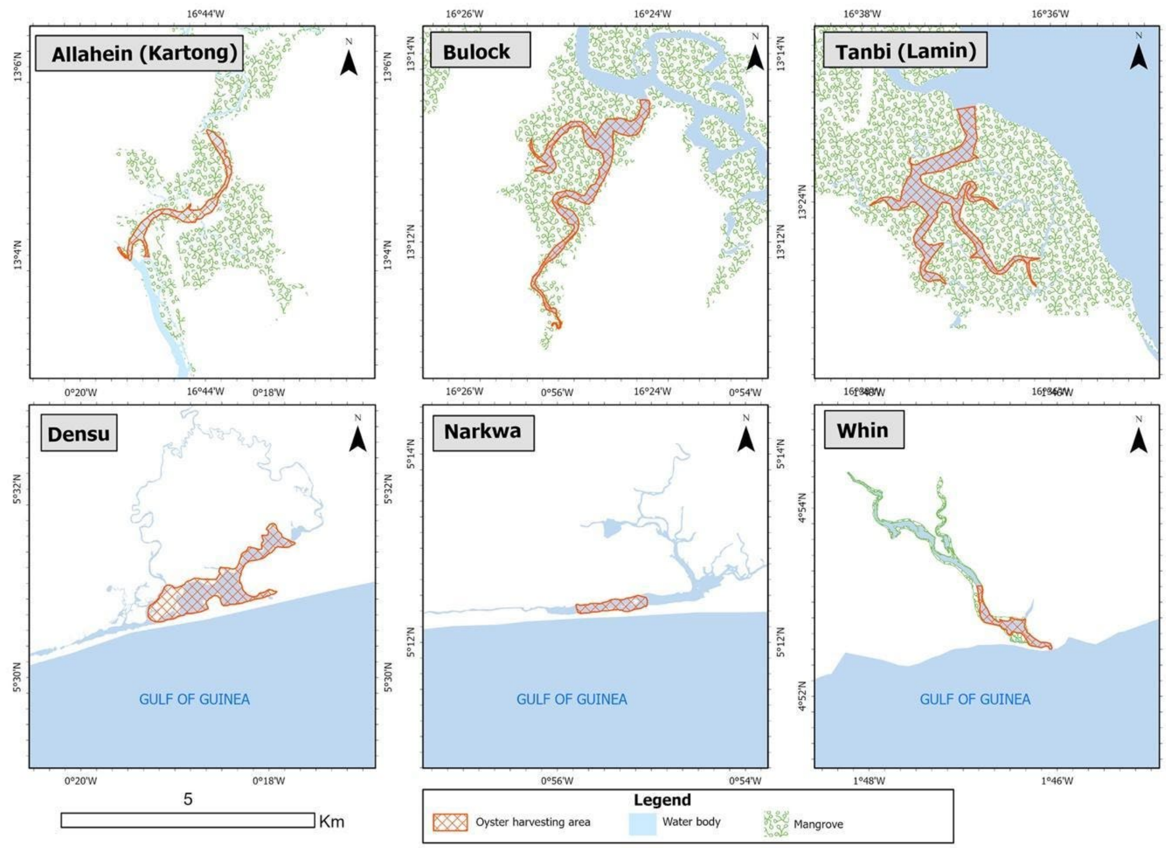


Figure 44: Aerial maps of the six study sites showing the extent of mangrove cover and shellfishing areas (in red line) for each site.

Results of analyses of the fishing intensity (Table 5, Figure 45) showed that Narkwa had the highest fishing intensity, followed by Whin with the lowest in Ghana being Densu. The Tanbi had the overall lowest fishing intensity of 0.04 harvesters/m^2, about ten times less than the fishing intensity at Narkwa.

Table 5: Summary of total shellfishing area, number of harvesters and approximate index of fishing intensity at the six sites.

Site	Total shellfishing area (Km^2)	Total number of women harvesters	*Index of harvesting intensity [(no. of harvesters/Area)/1000]*
Allahein	0.52	125	0.24
Bulock	1.20	80	0.07
Tanbi	1.70	70	0.04
Densu	1.43	200	0.14
Narkwa	0.27	100	0.37
Whin	0.29	84	0.29

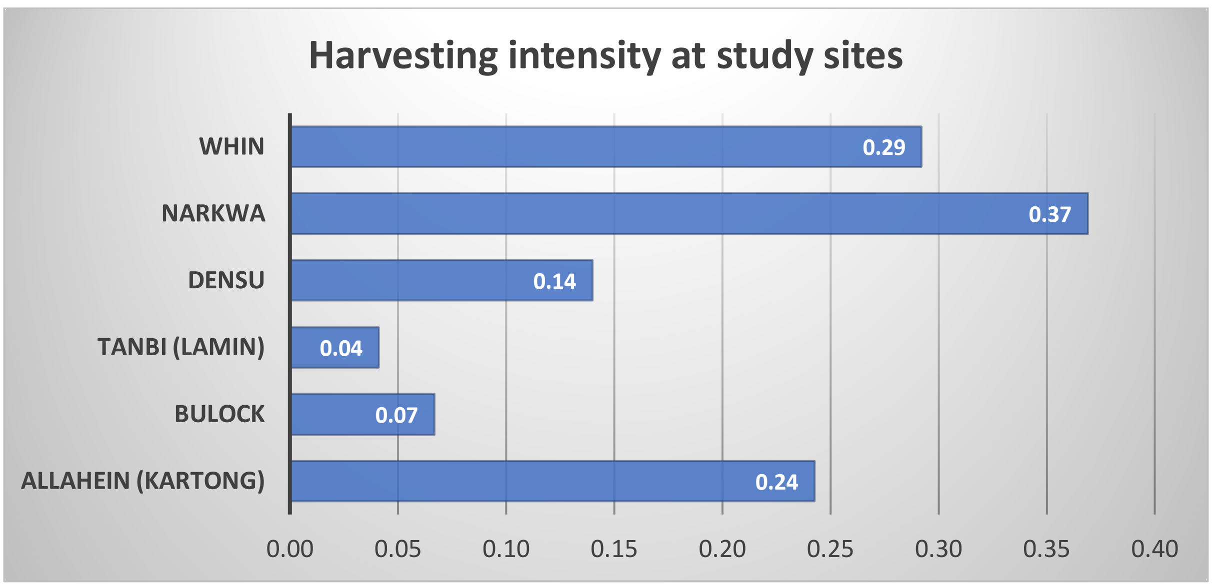


Figure 45: Oyster harvesting intensity (harvesters/m2) among the six study sites.

3.6 Socioeconomics and governance of the oyster fisheries

3.6.1 Socio-economic analyses of the oyster fisheries

A household socio-economic survey of oyster harvesters was conducted at the sites of the research. Table 6 provides a summary of all indicators of poverty/wealth and women empowerment towards the successful co-management of the estuarine and mangrove ecosystems. The Tanbi had highest poverty scores (higher score means less poverty) and household wealth measures and more empowered women oyster harvesters compared to the all the other communities studied. The women shellfish harvesters of Tanbi were comparatively well-off considering the poverty indicator, wealth measure by household structure, and household income. In the Tanbi enclave, the earnings from shellfishing, and its contribution to household income, is relatively more significant, constituting more than half of the total income for the households of women shellfishers. These women are also the most empowered of all the six sites studied. They had the highest score in relation to decision-making on the management of their shellfisheries. However, like the other communities except for Densu, shellfish harvesting involved excessive workload.

Table 6: Summary of mean scores on socio-economic indicators for poverty, wealth and women's empowerment in the six study sites.

Measured indicator	The Gambia				Ghana				Reference Score Range
	Allahein	Bulock	Tanbi	Country Average	Densu	Narkwa	Whin	Country Average	
Poverty/wealth measure									
Poverty indicator	1.67	3.36	4.22	3.08	2.83	2.20	2.52	2.52	0 – 7
Wealth measure by household structure	2.67	3.21	3.44	3.11	3.00	2.60	3.14	2.91	0 – 4
Household income	2.92	2.96	3.89	3.26	2.00	1.85	2.33	2.06	1 – 6
Livelihood dependence on shellfisheries	1.21	1.64	2.22	1.69	1.11	2.15	1.48	1.58	0 – 3
Women's empowerment measure									
Production: Decision making on shellfishing	3.17	3.30	3.78	3.42	3.06	1.60	2.00	2.22	0 – 4
Resources: Access to and decision making of assets and credit	0.92	1.14	3.00	1.69	1.22	0.65	0.76	0.88	0 – 4
Income: Control over use of income	1.96	1.26	2.67	1.96	2.89	2.90	3.00	2.93	0 – 3
Leadership: Group Membership	2.63	2.78	3.00	2.80	2.78	0.05	0.00	0.94	0 – 3
*Time: Workload from shellfishing**	Excessive	Excessive	Excessive	Excessive	Adequate	Excessive	Excessive	Excessive	+/- 10.5 hrs.
Total for the measure of women shellfishers' Empowerment	*8.68 + Excessive workload*	8.48 + Excessive workload	12.45 + Excessive workload	9.87 + Excessive workload	9.95 + Adequate workload	5.20 + Excessive workload	5.76 + Excessive workload	6.97 + Excessive workload	0-14 and +/- 10.5 hours workload

*If mean hours per site is less than 10.5 hrs. spent in shellfishing, workload is adequate, otherwise inadequate.

3.6.2 Governance structures and management modalities

Focus group discussions were conducted with key informants to solicit site-specific information on the shellfishery, governance regimes and management structures, with issues discussed broadly covering the scope and state of the shellfishery, harvests, access, condition of mangroves, governance, and management regimes, among others. Table 7 summarizes some key outcomes of the discussions concerning the shellfishery. In Ghana, the majority of the women involved in shellfishing activity are within the Densu estuary while in The Gambia most of them are in Allahein although the women harvesters in the entire Tanbi may outnumber the other sites as there are several communities fringing the Tanbi wetland, and only a few of the thirteen shellfishing communities in the Tanbi were surveyed (with most of the women being from Lamin) in this sample. Aside from shellfishing as their main livelihood, some of the women are also involved in farming, trading, and fish processing. Most of the women in both countries harvest every day in the season and less than half is kept for household consumption. There have also been changes in the harvesting patterns in most communities except in Whin within the past 10 years - in terms of harvesting time, quantity harvested, and distance to harvesting location.

Except for Whin and Narkwa in Ghana, where there are no existing structures for governing the oyster fishery, the other four sites have varied levels of governance structures and management mechanisms for the fishery, ranging from largely shellfisher and community led management regimes (Allahein and Bulock), to formalized co-management regimes with exclusives use rights granted to the shellfishers by government (Tanbi and Densu) and a guiding co-management plan (Table 8). The management modalities cover seasonal closures, size limits (smaller ones deemed immature not to be harvested), protection and restoration of mangroves, among others. There are however no restrictions on number of harvesters and quantities to be harvested or any form of quotas even though the management plan allows for such provisions within a use rights scheme. In Densu for instance, respondents noted,

"There is a seasonal closure (from our co-management plan) for when to harvest. There is no limitation on how much can be harvested. We harvest only the adult or bigger ones, spat are left behind."

Also, in Allahein, a respondent narrated,

"We don't harvest small ones", and in Tanbi "*there is a limit on the size one could harvest."*

It was interesting to know from Allahein that some form of area closures and occasional "no take zones" are implemented as well. A respondent narrated,

"They normally divide it, this year we take this side and then later we take that side."

It was noted that the governance systems did not necessarily restrict entry, but importantly take decisions which are approved by the community or government for implementation and ensure adherence to the rules governing the harvesting of the shellfish in the community. A respondent indicated,

"No one is excluded from the harvesting, outsiders can also harvest, but all harvesters pay GMD 500 each to the Village Development Committee in Bulock. Failure to pay, you will be prohibited by the Committee from harvesting."

With regards to the involvement of shellfishers in decision making, the sites with governance structures and management regimes strongly integrate the women shellfishers in decision making processes. For instance, *"Shellfishers have a say, they negotiate with the Village Development Committee on opening and closing of the season"* (respondents in Bulock), *"…yes, rules are discussed and agreed between shellfishers, TRY and Government (Fisheries Department)." (respondents from Allahein)*

"Yes, we have a say, contributed to the co-management policy and decide when to close the season" (a respondent from Tanbi)

On the contrary, women at the sites without governance regimes had no role in decision making as directives are usually given by Traditional Authorities. A respondent from Narkwa narrated,

"We are not considered in any rule making activities for the fisheries. We are not involved in any fisheries related rulemaking in the community."

At all sites, the respondents affirmed that mangroves were protected areas and further indicated that they are aware that cutting of mangroves in these areas are prohibited.

Table 7: Summary outcomes of selected issues in the Focus Group Discussions on the oyster fisheries at the six study sites in Ghana and The Gambia.

Site	No. of harvesters per community	No. of communities Involved in harvesting	Other sources of livelihood in addition to shellfishing	Frequency of harvest	Harvest per person per day	Proportion kept for consumption (percent)	Current harvesting hours per day	Changes in harvest between now and 5-10 years ago		
								Harvesting time	Daily catch	Distance to harvesting location
Densu	200	4	Fishing processing Head porting	Twice a week	Not estimated	30	~4 hours	Shorter time than current	3 times the current quantity	Increased
Narkwa	>100	1	Farming Fish processing	Every day in a season	40-60 kg	25-50	~5 hours	~3 hours	~80 kg	No change
Whin	84	4	Farming Trading	Every day in a season	60-80 kg	25	~10 hours	No change	No change	No change
Allahein	125	5	Farming	Every day in a season	40-105 kg	20	Not estimated	Shorter time than current	Fewer larger sized oysters	Increased
Bulock	80	12	Trading Farming	Every day in a season	105-630 kg	25	5-6 hours	1-2 hours	No change	Increased
Tanbi	70	9	Farming Trading	Every day in a season	350 kg	5	~6 hours	~3 hours	1050 kg	Increased

Table 8: Governance systems and management practices for the oyster fisheries at the six study sites in Ghana and The Gambia.

Site	Governance structures	Level of formal recognition and legitimacy	Management actions
Allahein	Women Shellfishers Association (also part of TRY Oyster Women's Association) in collaboration with community leadership	Largely shellfisher and community-led, with some level of Government support	Regulates harvesting of oyster, implements annual oyster closed seasons and protects mangroves
Tanbi	TRY Oyster Women's Association in collaboration with the Fisheries Department of the Ministry of Fisheries and Water Resources	Formalized and co-led by shellfishers and Government where shellfishers have been granted exclusive use rights to oyster and cockle fisheries	Regulates harvesting of oyster, imposes closed seasons and protects mangroves through a co-management plan/policy
Bulock	Village Development Committee (VDC)	Largely community driven with support of shellfishers	Regulates entry into the fishery, imposes closed seasons and protects mangroves
Whin	No governance structures	No existing governance regime	No organized management actions
Narkwa	No governance structures	No existing governance regime	No organized management actions
Densu	Densu Oyster Picker's Association and the Fisheries Commission of the Ministry of Fisheries and Aquaculture Development	Formalized and co-led by shellfishers and Government where shellfishers have been granted exclusive use rights to the oyster fishery	Regulates harvesting, implements closed seasons and protects mangroves through a co-management plan/policy

4. DISCUSSION

Results of this site-based in-depth research in Ghana and The Gambia unravels the dynamism of the West African Mangrove Oyster (*Crassostrea tulipa*) fishery, ranging from variability of seasonal and site-specific ecological conditions and biological stocks to dynamics in exploitation, livelihoods, and socio-economic status of the shellfishers, as well as varied levels of structures for governing and managing the oyster fisheries across sites. Given the complicated interrelationship between these variables where some (e.g., the environmental conditions, exploitation, and management modalities) act as drivers of change in others (e.g., health of stocks, livelihoods, and socio-economic well-being) in a cyclical or looping socio-ecological system context, results of this study strengthens the evidence base for fostering participatory co-management of shellfisheries in West Africa.

4.1 Water quality conditions and their possible effects on the oysters

In interpreting results of the current study, it is important to note that although the sampling was not strictly based on tides, diurnal tides may have influenced results as tidal regimes occurred during the sampling period. From the results of the physio-chemical assessment, The Gambian systems were generally deeper than Ghanaian waters, with the deepest being the Tanbi Wetlands, and shallowest being the Whin Estuary. In addition, salinity which is one of the most important environmental factors for survival and growth of the oysters, was more stable in The Gambian systems within a range of 20 ppt and 40 ppt throughout the year, compared to the Ghanaian systems where salinities fluctuated widely between freshwater and marine conditions, almost 0 ppt in all systems during the rainy season in June. These salinity ranges are in consonance with the thriving conditions reported for *C. tulipa* in the region (Chuku et al., 2020; Mahu et al., 2022; Osei et al., 2021). The shallower nature of the Ghanaian systems and high influx of freshwater likely accounts for the high fluctuation in salinity and the extremely low salinities during the rainy season. Salinities below 4 ppt and above 50 ppt are potentially detrimental to growth and survival of *C. tulipa* while prolonged exposure to a salinity of 0 ppt causes mortalities (Mahu et al., 2022). The very low levels of salinity near 0ppt recorded in June, September, and November 2021 at Densu can be detrimental to the growth and survival of oysters through physiological stress (Osei et al., 2021).

Aside from salinity, turbidity, which is another critical factor due to the filter feeding habit of oysters, was low in Gambian waters and much higher in Ghanaian waters, generally highest in the Whin Estuary, although within the tolerable limit of 350 NTU for the oysters. Suspended silt, when filtered by the oyster, smothers the gills, hampers the flow of food during filter feeding and leads to mortalities. Also, copious silt in water could trigger oysters to clamp their valves and reduce the feeding rate, thereby slowing metabolism and resulting in a retardation of growth.

Nutrient levels at the six sites were generally comparable, except for September 2021, when there was a much higher influx of nutrients in The Gambian waters than the Ghanaian waters (especially nitrates). In general, the nutrients exceeded the optimum levels of 0.1 mg/l phosphate and 1.0 mg/l nitrate reported as the suitable levels for primary productivity in estuaries and other coastal ecosystems (NOAA/EPA, 1988). However, nitrate which is the limiting nutrient in seawater, did not exceed levels beyond 5 mg/l that could drive harmful algal blooms in the systems, aside from the high levels above 10 mg/l in the Gambian systems in September 2021. The higher influx of nutrients during this period which coincides with the peak of rainfall likely could be from sources such as nitrate and phosphate-based fertilizers applied during the agricultural growing season which enter the water bodies through run-offs, human wastes and animals entering the estuaries.

It is possible that the lower turbidity (i.e., higher transparency) in The Gambia waters would allow for higher light penetration and hence higher primary productivity resulting in the availability of food for the oysters, although primary productivity was not assessed. The abundance of food (phytoplankton) coupled with low turbidity (i.e., low levels of suspended silt) will engender efficient and higher filtration rates, enhancing oyster feeding and growth in the systems in The Gambia compared to Ghana. All these comparative differences in environmental factors possibly contributed to the observed larger modal sizes (around 6cm SH) of oysters in The Gambia than in Ghana (about 4cm), with the exception of oysters in the Densu Delta that compared with The Gambian oysters.

The optimum ranges of estuarine conditions for survival, growth, metabolism and feeding efficiency of *C. tulipa* are not available. Nonetheless, the species is recorded to thrive in a range of conditions along the coast of West Africa. Temperatures recorded in the *C. tulipa* habitats in this study were within the tolerable range of 15°C to 36°C for most tropical oysters (Gosling, 2015). Salinities recorded in The Gambian and Ghanaian waters were also largely within the tolerable for the oysters as the species is euryhaline, (Asare et al., 2019; Chuku et al., 2020).

Reports indicate that *C. tulipa* thrives in varied dissolved oxygen (DO) concentrations in different systems, surviving in estuarine conditions from 10 mg/L to as low as 1 mg/L (Chuku et al., 2020; Osei et al., 2021; Mahu et al., 2022). DO concentrations at the sites were above 2 mg/l in all systems, a level possibly above the low concentrations stressful to the oysters in the systems.

4.2 Coliforms and heavy metals

Coliforms, fecal coliforms, and *Escherichia coli* occurred in both water and oyster tissue at all sites. Comparatively, higher total coliform count was recorded in the waters at the sites in Ghana than The Gambia. Comparing the results to the US National Shellfish Sanitation Programs' approved standards for total coliform (70 CFU per 100 ml) and fecal coliform (14 CFU per 100 ml) in the waters of shellfish growing areas (NSSP, 2019), the total coliform and fecal coliform (including *E. coli*) were largely within the approved standards, except at the peak of the rains in June 2021 at the sites in Ghana, and September 2021 in the Tanbi, where fecal coliforms in the water and oysters reach the 14 CFU per 100 ml limit. However, *E. coli* levels were very low in the tissues, reaching virtually 0 CFU/100ml in nearly all quarters.

There was a strong positive correlation ($r = 0.69$; $P = 0.002$) between total rainfall and the concentration of *E. coli* in oyster tissues indicating that rainfall largely influences the coliform loads in the systems as most peaks of mean coliform concentrations were recorded in June and September 2021. Rice et al. (2015) reported that fecal coliform values from most shellfish growing areas in the Tanbi and Allahein were within the US-NSSP standard of 14 CFU per 100 ml most of the year, indicating clean growing waters, and highest average fecal coliform values corresponded to local rainfall maxima from July to October during the traditional closed season for shellfishing, similar to the results of the current study at the Gambian sites. Results of the rainfall data showed the peak in The Gambia in September, which is also coincides with the peak of coliform loads in oyster tissues. The peak coliforms in The Gambia are periods when the fishery is closed at all sites, hence posing no health and food safety threat.

Similarly in Ghana, the peak of rainfall does occur in June –July when coliform levels are also high. Oysters are harvested during this period, and therefore could be a time of high risk for oyster consumption. The period of high coliform levels may be a period to consider for closure to minimize human health risks from consumption. It is however important to mention that oysters are steamed open and then shucked before consumption in both countries. This likely lowers the risk of consuming any potential live pathogens harbored in the raw oyster meat, although it is unclear if the cooking temperature is high enough to kill off the coliforms, and therefore, could be an area of future research.

Although coliform concentrations were low, their occurrence suggests a close proximity of the estuaries and the mangrove systems to human activities of the communities fringing these waters, such as raising of pigs within intertidal areas and inflows of human waste as indicated by Rice et al. (2015). The active fishing activities and frequent navigation along the banks and across the Allahein, the active tourist activities on the Tanbi system, and similar active human and fishing activities and waste disposal along the Densu, Narkwa, and Whin could be the main source of the fecal coliform and *E. coli* in the waters and the oyster flesh. Especially with these sites being urban areas with a considerable level of human activities, the likelihood of unhealthy human activities along the boundaries of these systems is high, culminating into the observed *E. coli*. Probably the isolated location of the Bulock waters from the community, which is also rural, could account for the low *E. coli* load occurring in the oyster tissue in only one quarter at this site.

The occurrence, sources and human health implications of toxic metals (manly mercury, lead, cadmium, chromium and copper) in estuarine environments are explained by the United States Environmental Protection Agency (EPA, 2006). Although there are natural sources of these metals, anthropogenic sources contribute significantly to elevated levels in aquatic ecosystems. Mercury contamination originates from solid waste, municipal wastewater treatment plants and mining and industrial sources, while sources of lead are batteries, paints, solder, and in building construction. Cadmium may originate from solid waste, batteries, tires, and many industrial processes. Chromium is mainly emitted into the atmosphere through manufacturing industries and natural gas and oil combustion, and may reach waterbodies through road dust, cement-producing plants, asbestos sources, municipal refuse and sewage, automotive exhaust, waste waters from leather and textile industries and solid wastes from chemical manufacture.

In the current study, the levels of Mercury, Arsenic, and Chromium were largely within WHO permissible limits in the oyster tissue although some occurred above permissible limits in the water. Lead and Cadmium were above the acceptable limits in the oyster tissues. Other studies have similarly reported high levels of particularly lead and cadmium above permissible limits, in the tissues of oysters and other shellfish in estuarine systems [see Bodin et al. (2013) in Senegal; Catry et al. (2021) in Guinea-Bissau; Solitoke et al. (2021) in Togo; Vázquez-Sauceda, et al. (2011) in Mexico, among others]. This could possibly be a result of abundance of these metals in the waters and resultant bioaccumulation in the shellfish over seasons (EPA, 2006).

Some studies in West African coastal lagoons and estuaries have reported seasonal variations in the concentration of heavy metals in these systems. For instance, higher concentrations of Cd, Cr, Cu and Pb were found in the sediment of the Lagos Lagoon during the dry season than the wet season (Oyeyiola et al., 2014; Oyeyiola et al., 2013). These studies suggested a possible accumulation of the metals in relatively labile forms in the sediment during the dry season and can be released and transported or bioaccumulated in the rainy season. This corroborates some results of the current study, where the concentration of cadmium in the water was high and above permissible limit at all sites in the dry season in March and December 2021 but reduced below permissible limit during the wet season in June and September. The reciprocal occurred in the oyster tissues where elevated levels of cadmium were rather recorded during June-September, consistent with Solitoke et al. (2021) where the highest concentration of cadmium in oyster tissue was recorded in June in Zowla-Aného lagoon in Togo. The other metals showed no clear patterns although some (e.g. As, Hg, Pb) seemed to be somewhat higher in the water and lower in the oysters during the rainy season and tend to be reducing in the water while increasing in the oysters in the dry season, possibly from accumulation.

Results of a similar heavy metal study carried out on oyster tissues at the Densu, Narkwa and Whin during June-July 2021, the same period as the second quarter of the current study, reported heavy metals in oyster tissues to range from 4.75-36.3 mg/kg for cadmium, 13.6-17.6 mg/kg for lead, and 22.1-64.9 mg/kg for mercury (Adu-Afarwuah et al., 2022). These values were much higher than the results of this current study where all recordings were below 1mg/kg. It is unclear why samples collected from the same waters around the same period could differ significantly in the results. Considering the conflicting results, further investigation with split samples analyzed in different ISO certified laboratories could be helpful in confirming the levels of the metals in these systems.

The results of high concentration of heavy metals in the oyster tissues especially lead and cadmium which were above the WHO acceptable levels raise serious concerns as these contaminants tend to put consumers health at risk. EPA (2006) outlines the health threats posed by lead poisoning, and this includes kidney damage, anemia, and damage to the central nervous system, as well as permanent physical and mental impairments in children. Cadmium can also cause kidney and bone damage to people who suffer long-term chronic exposure. It is therefore important to curb activities at these sites that are potential sources of these toxic metals in the water and the oyster. The lead could be originating from painting of boats at the banks or paints on the boats used on these systems for fishing at Allahein, navigation and tourist activities on the waters of Tanbi, and waste disposal along the Densu, Narkwa, and Whin. The multiplicity of industrial activities within the catchment of Tanbi, Densu and Whin which are located in urban areas could also be the potential sources of the heavy metals in the systems. In the Whin estuary, the extremely high concentration of Mercury during the rains in June 2021 is probably attributable to the upstream illegal gold mining activity that silts the estuary through runoff.

4.3 Sizes, reproduction, growth, condition and possible impacts of management measures on the oyster populations

The largest oysters were found at Densu with an overall mean shell height of 6.82 cm, followed by Bulock (6.49 cm), Tanbi (6.17 cm), Allahein (6.13 cm), Whin (6.10 cm) and Narkwa (4.60 cm). Also, Bulock oysters had the largest maturity size (5.6 cm), and was followed by Densu (5.4 cm), Allahein (5.3 cm), Tanbi (5.2 cm), with smaller maturity sizes occurring in Whin Estuary (4.9 cm), and the smallest in Narkwa Lagoon (3.6 cm). This is consistent with the results of the probability of capture (L_c/L_{50}) from the stock assessment where oysters of size 4.9 - 5.8 cm SH have 50 percent probability of being harvested in The Gambia while these sizes are smaller in Ghana (3.7- 4.8 cm SH) with the smallest being 3.7 cm in Narkwa. It is noteworthy that the mean sizes of oysters are all above the maturity sizes. This indicates that growth overfishing (harvesting smaller oysters before they attain reproductive size) is unlikely but rather recruitment overfishing (excessive harvesting of the spawning stock) is driving overexploitation at the overexploited sites. Measuring length-frequency of oysters actually harvested could help confirm this finding. Among the six sites, the Narkwa oysters were the stock harvested at the smallest size, measuring about half to one-third the sizes of oysters harvested at all the other sites.

The implementation of seasonal closures by the shellfishers, community leaders and the Government at Densu in Ghana and all the three sites in The Gambia provide a very useful participatory effort in the management of shellfish resources. Such management actions are mainly intended to allow for reproduction, growth, and improved condition of the oysters before harvesting. The management measures cover widely seasonal closures, prohibiting harvesting of small-sized oysters deemed immature, protection and restoration of mangroves, among others. These measures implemented at Densu, Bulock, Tanbi and Allahein possibly accounts for the larger oysters maturing around 5 cm at these sites, compared to the 4 cm at Whin and Narkwa where no such management regimes exist. This is possible because high fishing pressure is known to have a bearing on reduced maturity size, with the latter being used as an indicator of the former (Lappalainen et al., 2016) as the early gonadal maturation and spawning becomes the adaptive mechanism for surviving the high fishing pressure.

It could be noted from the monthly size variation data that a drastic decline in mean sizes (SH) were recorded between May and June at the sites (between March and May for Whin), which could not be attributed to fishing pressure as this occurred at sites with closures and unmanaged sites. This sudden decline in mean sizes in May-June possibly points to a result of the entry (recruitment) of large number of smaller oysters into the stocks as a result of reproduction (spawning) in the earlier months, as monthly mean sizes progressively increased at all the sites after May-June suggesting growth of the oysters after the recruitment period. Results of both the monthly length-frequency distribution analyses and the sex ratio largely support this April-June recruitment as well. The length-frequency distributions show the occurrence of smaller oysters around 4 cm SH, that is new recruits, constituting the modal sizes in Allahein (March and June), Bulock (June), Tanbi (April-July but significantly June), Densu (May), Narkwa (March-May) and Whin (May-July). The highest proportion of oysters with indeterminate sex (juvenile recruits and spent adults) were recorded in all the systems within this period. From the histological examination of the mature oysters, the steep decline of the Gonad Index (GI) between March and June 2021 especially for the Gambian stocks indicates major spawning during this period; although a continuous spawning is more prominent at the Ghanaian sites.

As noted earlier, management measures are implemented to allow for reproduction, growth, and improved condition of the oysters prior to harvesting. The timing and period for closing and opening the seasons is therefore very important in meeting these biological objectives for enhanced economic gains. Delving into site specific data from this research, the Densu oyster fishery was closed in late 2020 and opened in May 2021, and then closed again in November 2021, and opened in late April 2022. The latter marks the fifth closure since implementation of co-management of the fishery. In The Gambia, the season was opened for Tanbi and Bulock for only two to three months between March and June 2021 but was closed the whole year for Allahein.

Clearly, the spawning and recruitment period partly overlaps with period for opening of the season, especially in the Gambia where the opening is mainly informed by the high demand for oysters during the Ramadan festive period in March-April. It is therefore very useful that the management measures at the sites already prohibit the harvesting of smaller oysters upon opening of the season as this will importantly protect the spat (recently settled oysters) to allow for recruitment. Such management measures will also be useful for improving the stocks at the currently unmanaged sites, especially Narkwa where the oysters harvested are the smallest. At all sites, it is important that a strict adherence to harvesting at sizes not smaller than the maturity size is enforced to allow for growth and replenishment of the stock. For Narkwa, setting a size limit at a larger size than the maturity size would be precautionary and allow for even greater abundance of spawning stock biomass.

The Condition Index (CI) of bivalves measures the extent to which the meat fills the shell (Quayle 1980). This provides a useful measure of the degree of fatness or the commercial quality of the species (Davenport and Chen, 1987), hence, monitoring the CI of oysters could help harvesters determine the most suitable time(s) of the year for harvesting (Yankson, 2004). The CI could also provide important indications on reproductive processes (Hickman and Illingworth, 1980; Thippeswamy and Joseph, 1988). In the current study, the opening of the season in March 2021 in The Gambia coincided with a high Condition Index of the oysters during the harvesting period, and this possibly optimizes the gains on harvests for the women. Similarly, the peaks in CI observed between June and September 2021 for the Densu stocks enables shellfishers to optimize the harvests of oysters in good condition for possible economic benefits, while the CI peak observed after the season closed in December 2021 is helpful in preparing the oysters for spawning in subsequent months. Therefore, the current timing of closed seasons implemented at Tanbi, Bulock, Allahein, and Densu each year are largely helpful in protecting gravid adults and allowing for spawning, and at the same time optimizing the gains from harvesting oysters in good condition.

4.4 Possible impacts of management modalities at the sites on the status of the oyster fisheries

The results of the exploitation ratio of the stocks indicate that Densu and Tanbi oyster stocks are under exploited, Whin and Allahein are optimally exploited while Narkwa and Bulock stocks are overexploited. For Tanbi and Densu, the under-exploitation status could be attributed to the existence of the already discussed management regimes for the fishery at these sites, mainly implementation of closed seasons and size limits. Likewise, the lack of management and exploitation of very small oysters at Narkwa accounts for the overexploited state of the fishery. These results are also corroborated by the results on harvesting intensity at the sites which show Tanbi with the lowest fishing intensity and Narkwa with the highest. The optimally exploited stocks at Whin and Allahein are also deemed reasonable outcomes and a practical reflection of the situation of the fishery when compared with data on mean sizes, maturity sizes, and sizes at 50 percent probability of capture. However, the situation of overexploited stocks at Bulock is rather unclear to explain, especially as the second largest mean size, largest maturity size and largest oysters at Lc/L_{50} were all recorded at Bulock. A possibly further longer period of data beyond one year could be helpful in evaluating and confirming this result. However, given the conflicting data, a precautionary approach that strengthens co-management of size limits and seasonal closures would seem prudent.

4.5 Possible impacts of existing governance mechanisms on the women shellfishers

Further anchoring the discussion around the benefits of co-management of shellfisheries, a general trend of better living conditions, and an empowered women community of oyster harvesters was identified for the Tanbi among all the communities studied. The women shellfish harvesters of Tanbi are comparatively better off considering the poverty indicator, wealth measure by household structure, and household income. In Ghana, Densu also had the most empowered women among the other sites. Notably, these are the two sites with formal governance backed by Government's delegation of exclusive use rights, although the wealth and empowerment of the women at both sites may be confounded by other factors given their proximity to large urban centers; the capital cities.

Tanbi and Densu were followed by the other sites with governance structures and modalities for managing the oyster fishery, although the Whin shellfishers also compared favorably, with Narkwa shellfishers being the worst. This also reflects in the higher mean scores for the socio-economic indicators for The Gambia than Ghana shellfishers. The women shellfishers at the sites with governance structures and management regimes were also strongly involved in decision making processes, taking stewardship for decisions on the resource and its management. These benefits of women integration in fisheries governance and decision making at the Densu, Tanbi, Allahein, and Bulock, driven partly by their stewardship for the oyster fishery resource through the Government's delegation of exclusive use rights to the women for participatory co-management of the fishery, presents an exemplary community of practice worth replicating along the West African coast. The ultimate outcome will be improved shellfisheries and wealth for such shellfish livelihood dominated communities and the countries as a whole.

5. CONCLUSION AND RECOMMENDATIONS

The six estuaries studied show mainly healthy bio-physical conditions. However, some aspects of the parameters studied raise concerns including; excessive nutrients, high levels of heavy metals in some sites, and overexploited shellfisheries in sites with no management systems. These areas of concern are caused by human factors and therefore, suggest the need for improved estuarine management that not only focuses on the shellfishery, but a more holistic perspective of the socio-ecological system.

High levels nutrients were recorded in the systems, generally exceeding levels considered optimal, and reaching levels that pose potential threat of nutrient pollution and algal bloom during the rainy season. This requires the implementation of programs to limit nutrient loading into the estuaries through targeted education on the appropriate application of fertilizers within the catchment of the waterbodies, and regulation of the proximity of agricultural farms to the waterbodies.

Fecal coliforms including *Escherichia coli* occurred in both water and oyster tissue at all sites, but do not currently pose a significant health threat for consumption of oysters at these sites based on the US-NSSP approved standards. However, as there are a few periods in some sites that are over the US standards. It suggests a need for longer baseline time series trends to be established and for consideration of closed seasons during known periods when levels are consistently above safe standards. Coliform levels may vary as well in different locations with each of these estuaries, as demonstrated by Rice et al., (2015), so spatial distribution as well as temporal distribution should be considered in further studies. Closed seasons due to elevated coliform levels may not be required throughout any given estuary and understanding the spatial dimensions could mitigate shellfish impacts of total closures at additional periods other than the current closures or if future value chain opportunities for sale and consumption raw oysters become available.

The concentrations of Lead and Cadmium were generally above the acceptable limits in the oysters, and given the human health threat these metals pose, the sources need to be identified and excessive loadings into estuaries addressed for public health and safety of shellfish consumption from these systems.

Management measures implemented at Densu, Bulock, Tanbi, and Allahein, mainly closed seasons and size limits were effective in yielding larger oysters at these sites, than Whin and Narkwa where no such management regimes exist. The closures protect gravid adults and allow for spawning, and at the same time optimizes the gains from harvesting oysters in good condition.

The results also demonstrate potential socio-economic benefits for women shellfishers where formal co-management and user rights regimes have been implemented. It presents opportunities on areas for channeling future efforts towards empowering the women shellfishers to sustainably manage the shellfisheries and improve their livelihoods. In Ghana, Narkwa requires critical attention as all indicators assessed, oyster sizes, maturity sizes, exploitation ratio, and fishing intensity point to an overexploited fishery which also reflects in the lowest socio-economic scores of the Narkwa shellfishers. Whin and Bullock are systems also in need of management attention, as Whin stocks are optimally exploited and Bulock is overexploited. These importantly present the opportunity for extending the co-management and use rights schemes at Densu to Whin and Narkwa through peer to peer influence and capacity development exchanges between the Densu Oyster Pickers Association and the Whin and Narkwa shellfishers, possibly facilitated by DAA. Similar modalities are also necessary for Bulock, between the Tanbi and Bulock shellfishers, facilitated by the Try Oyster Women's Association.

The following specific recommendations are made:

1. The line ministries for Agriculture in Ghana and The Gambia should consider extension efforts with farmers for education on appropriate application of fertilizers within the catchment of these systems and demarcate buffer vegetative zones along the water bodies to mitigate nutrient runoff.
2. Further studies on sources of the heavy metals in the system especially Lead and Cadmium is necessary in understanding the sources and how this could be addressed. Government should consider more holistic ecosystem based estuarine management that includes management of water quality issues of concern to maintain healthy estuaries and associated fisheries.
3. Both The Gambia and Ghana should consider establishing some form of simple shellfish sanitation monitoring and management programs in estuarine areas.
4. Closed season needs to be implemented at Whin and Narkwa and given the partial overlap of the spawning period of the oyster populations with the harvesting season in The Gambia, a shorter harvesting season targeting two months of high demand for the Ramadan and not extending into June, could be considered. Enforcement on harvesting at sizes not smaller than the maturity size at all sites would also be helpful, and for Narkwa in particular, setting a limit at a larger size than the maturity size would be precautionary and allow for even greater abundance of spawning stock biomass.
5. For long term data-driven decision making on each fishery, it will be necessary for the Fisheries Commission of Ghana and the Fisheries Department of The Gambia to support the women in establishing cost-effective participatory shellfisheries data collection modalities in collaboration with the academia (importantly UCC). This could focus primarily on production data with occasional data on size or growth.
6. It is important to create opportunities for peer to peer engagement and learning between shellfishers at co-managed sites and shellfisher at sites with no management modalities to initiate steps toward instituting management modalities of the shellfisheries at the unmanaged sites.

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APPENDIX 1: Survey Instrument for the socio-economic assessment of individual shellfishers

1. Poverty indicator (adapted from the poverty probability index):

Question	Yes (1)/ No (0)
1. Are there less than 6 members (1-5 members) in your household?	
2. In the past month, have you purchased one or more chicken eggs?	
3. In the past month, have you purchased any beef or corned beef?	
4. Is the main fuel used by the household for cooking gas or electric or something other than wood, crop residue, sawdust, or animal waste?	
5. Does any member of the household own a refrigerator?	
6. Does any member of the household own a fan?	
7. Does any member of the household own a television?	

>>> Poverty score: Yes = 1 No = 0 Possible score ranges from 0-7. The higher the score the wealthier the household, the lower the score, the poorer the household.

2. Wealth measure based on house structure (adapted from the women's learning initiative):

2.1. What materials is the roof of your house/ dwelling made of:

Score	Materials
0	Light materials (leaves, thatch, cardboard, earth-mud bricks, Salvaged/makeshift materials) Mixed but predominantly light materials Mixed but predominantly salvaged materials
1	Mixed but predominantly strong materials
2	Strong materials (galvanized iron, aluminum, tile, concrete, burned brick, stone, asbestos, wood, plywood)

2.2. What materials are the walls of your house/dwelling made of:

score	materials
0	Light materials (bamboo, leaves, thatch, cardboard, earth-mud bricks), Salvaged/makeshift materials, mixed but predominantly light materials, Mixed but predominantly salvaged materials
1	Mixed but predominantly strong materials
2	Strong materials (galvanized iron, aluminum, tile, concrete, burned brick, stone, wood, plywood, asbestos)

>>> Wealth score based on household structure. Sum the scores for the roof and wall materials. Range 0-4. Higher the score the wealthier the household

3. Household income (adapted from the women's learning initiative):

Score/rank	Over the last year, how much did your household earn in an average week from all productive activities/livelihoods in the household?
1	0 - 50 Cedis/ 0-500 Dalasi
2	51-100 Cedis/ 501-1000 Dalasi
3	101 - 250 Cedis/ 1001-2500 Dalasi
4	251- 500 Cedis/ 2501-5000 Dalasi
5	501 - 2000 Cedis/ 5001-20000 Dalasi
6	> 2000 Cedis/ >20000 Dalasi

>>> Higher the score/rank, wealthier the household

4. Livelihood dependency (adapted from Osei, Yankson and Obodai)

Score	How much of your household income over the last year was from shell-fishing related activities during the shellfishing?
0	Less than half
1	About half
2	More than half
3	All

>>> Shellfishing dependency is higher with a higher score

*** This question could be based with stones – show 4 stones and ask if this was their earnings from shellfishing, how many from shellfishing activities and how many from other. Then each rock is a quartile ranked from 0 -no rocks 0 %, to 4 -all rocks – 100%.*

5. Alternative livelihood options during lean/closed shellfishing seasons

During closed oyster harvesting seasons, what are your sources of income in order of importance: (this question would be interesting but no scoring so maybe not necessary)

Income type	Source of income	Income/day
Primary source of income (most important)		
Secondary source of income (second most important)		
Tertiary or lower source of income (third most important)		

Women's empowerment score (adapted from the Women's Empowerment in Agriculture index and Women's Learning Initiative) *It measures the roles and extent of women's engagement in the agriculture sector in five domains:* *1. decisions about agricultural production,* *2. access to and decision-making power over productive resources,* *3. control over use of income,* *4. leadership in the community, and* *5. time use.* *Adapted for shellfishing and limiting the questions to no more than 2 per domain:*

1. Production: Decision making on shellfishing

Score	For decisions about how the shellfishery is managed (e.g. deciding on timing of a seasonal closure).
2	I have input and women mainly make the decisions
1	I and other women have some input into the decisions
0	I and other women have no or little input, men make all the decisions
	For decisions on when, how and where I collect shellfish?
0	I have no input in the decision
1	I have a little bit of input
2	I mainly have input or make all the decisions

2. Resources: Access to and decision making of assets and credit

<u>Assets</u>	Our household owns a canoe or boat which I use to harvest shellfish
0	no
1	Yes
	I mainly decide when I use the canoe/boat for harvesting
0	No
1	yes
<u>Credit</u>	A person in my household is a member of a savings and credit group, or has a bank account
0	No
1	yes
	I mainly decide how much to borrow when I need credit
0	No
1	yes

3. Income: Control over use of income

In my household, I am mainly the one who makes decisions about how to spend the money earned from shellfishing

0	I disagree strongly
1	I disagree a little bit
2	I agree a little bit
3	I agree strongly

4. Leadership: Group Membership

Question	Yes (1) / No (0)
Are you a member of the local women's organization or shellfishing association	
Have you participated in a meeting in the last year?	
I am comfortable speaking in meetings to express my opinion.	

5. Time: Workload from shellfishing

Within 24 hours in the open fishing season, how many hours a day do you spend on:

Activity	Hrs.
Traveling to and from the collection site	
harvesting shellfish	
shucking or processing shellfish	
selling shellfish	
Sum the total hrs.	

>>> If less than 10.5 hrs. spent in shellfishing, workload is adequate. Code as binary 1= adequate 0 = inadequate

Scores on all 5 dimensions summed to get an overall score of women's empowerment.

APPENDIX 2: Semi-structured interview guide for focus group discussions

Name of Site____________________________

Country: _______________________________

Key informant Sex: Male __ Female __

Type:

__Women shellfisher

__Adult within a shellfishing household

__Local government official

__Other specify: _________________

Please describe the shellfishery in your area/community

1. What types/species are harvested: Oysters, clams, and/or gastropod or other?
2. How many people harvest these shellfish in the estuary/site? Consider all communities surrounding the estuary.
3. How many communities around the estuary are involved in harvesting?
4. Who harvests? Women and/or men and/or children?
5. Would you consider shellfish harvesters poor or well off?
6. Describe the livelihoods of the women and households involved in shellfishing.
    a. Do they only do this activity for a livelihood or do they have other livelihoods and sources of income? If other, what are they?
    b. Do they also fish in the estuary or nearby river or sea? If no, do other people in the community fish, and if so, using what gears and what types of species do they catch?
7. Is harvesting done every day? If not, how often is harvesting done in a month?
8. On average, what quantity can one person harvest in a day (kgs or other unit of measure such as a tin can, pail and approx. weight of unit of measure.)
9. Describe if there are seasonal variations in amount harvested due to rain or other seasonal events that may limit harvest and how does catch rates vary by season?
10. Are there months when no harvesting takes place? If yes, which months and why?
11. Describe how the product is harvested and whether boats are used and tools used if any.
12. How is the product processed? Boiled and shucked, kept while/fresh, shucked and dried or smoked or other process?

13. Describe the proportion of the harvest that is kept for family consumption and proportion that is sold.
14. If sold, where are the markets, distance to the markets, and prices per unit (pail, tin, handful, etc.)? Explain if prices vary by season or depending on how the product is processed?
15. Is there any aquaculture or farming of shellfish in the estuary? Or do seedlings get transplanted from one area to another?
16. Are the shells utilized? For what purposes? Are they ever returned to the estuary or places where shellfish is harvested?

Describe the condition of the fishery and how it has changed over time?

1. How long (hrs.) do people spend harvesting in a day?
2. Has there been any change in time spent on harvesting in a day over the last 10 years? Does it take longer, shorter or about the same amount of time to harvest the same amount today compared to 10 years ago? 5 years ago? How many hrs. in those other time periods?
3. How has the daily harvest quantities changed compared to 10 and 5 years ago? About the same, more or less and by how much – e.g., how many buckets today compared to 5 or 10 years ago?
4. Has the distance to get to the harvesting locations changed compared to 5 and 10 years ago? How? Longer or shorter distance, or same, and why?

Describe how the shellfish are managed

1. Are there any rules for when or how or how many shellfish you can harvest? If so, please describe. Seasonal closures, area closures, size limits, harvesting limits
2. Are these rules applied via tradition or set by local traditional leaders, among the shellfishers themselves or are they enacted by government?
3. Can people be excluded from harvesting, in other words, is only a select group in the community allowed to harvest? Explain? What about people coming from outside the community?
4. Is there a formal management plan for the shellfisher? How was it prepared and is it being followed?
5. If there are any harvesting rules or exclusive rights to fishing, to what extent are these followed and how are they enforced?
6. Explain whether shellfishers have any say in how the rules are established or changed? How?
7. Is the estuary and mangroves a protected area (e.g., park or reserve declared by government?

Describe the uses and condition of mangroves in your area

1. To what extent are mangroves harvested in the estuary?
2. By whom? Men, women, community members or people outside the community? Used for household only or sold in or outside the community?
3. How much do they earn in a given day if sold?
4. Mangroves are used for what purposes? Such as fuel wood for cooking smoking fish, building construction, sold for cash in local towns, medicinal or dying preserving cloths or fishing nets? other?
5. Compared to 10 and 5 years ago, have the condition/health of the mangroves changed? Degraded, regenerated, or about the same. Extent they have been cut or replanted or naturally regenerated? Are the changes due to cutting or other causes – natural or filling for settlements or businesses? Explain.
6. Are there any rules or prohibitions of using mangroves? Explain? By whom – local, traditional, government?
7. Are mangroves protected by law (e.g. illegal to cut?)
8. How are they managed – local traditional by a government agency?
9. What needs to be done to maintain a healthy fishery and mangroves?
10. How can the livelihoods of shellfishers be improved?