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DIETARY INTAKES, FOOD SECURITY, AND ANEMIA PREVALENCE AMONG WOMEN SHELLFISHERS IN SELECTED ESTUARY SITES IN GHANA AND THE GAMBIA

University of Ghana Milestone #10: Technical Report of Findings on Activity 2e and contributions to Activity 2d

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Cover photo: A woman shellfisher holding an oyster in its shell.

Photo credit: University of Ghana

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ACRONYMS

ADC	Average Daily oyster Consumption
ABW	Average Body Weight
CCM	Centre for Coastal Management
CRC	Coastal Resources Center
DDS	Dietary Diversity Score
EDI	Estimated Daily Intake
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FCT	Food Composition Table
HFIAS	Household Food Insecurity Access Scale
HI	Hazard Index
LPG	Liquified Petroleum Gas
MDD-W	Minimum Dietary Diversity for Women
RDA	Recommended Dietary Allowance
RfD	Oral reference Dose
SD	Standard Deviation
THQ	Target Hazard Quotient
UCC	University of Cape Coast
URI	University of Rhode Island
USAID	United States Agency for International Development
WPS	Wealth-Poverty Score

DIETARY INTAKES, FOOD SECURITY, AND ANEMIA PREVALENCE AMONG WOMEN SHELLFISHERS IN SELECTED ESTUARY SITES IN GHANA AND THE GAMBIA

SUMMARY

Introduction: Oyster shellfishing offers a rich source of iron and other nutrients for women shellfishers in Ghana and The Gambia, where anemia prevalence among women remains high. Success at oyster shellfishing depends on appropriate management of local shellfisheries resources. In estuarine communities where the local shellfisheries resources are poorly managed, decreased oyster yields and availability could deny women shellfishers of a potentially vital resource for income and the prevention of household food insecurity, low dietary diversity, and anemia. We aimed to compare nutritional outcomes among women shellfishers 15-49 years of age living at three estuary sites in Ghana and The Gambia. We hypothesized that within each country, lower household poverty and higher oyster consumption (potentially resulting from increased oyster yields due to improved management of shellfisheries resources) would be associated with: (a) lower household food insecurity, (b) greater likelihood of achieving minimum dietary diversity for women (MDD-W), and (c) lower prevalence of anemia. In addition, we aimed to determine the mineral and heavy metal concentrations of oysters collected from three estuarine sites in Ghana and evaluate whether heavy metal contamination is of concern to the health of women shellfishers at these sites.

Methods: We conducted two cross-sectional surveys, one in Ghana and one in The Gambia. Within each country, the study participants were women shellfishers 15-49 years of age living at three oyster estuary sites selected according to three levels of mangrove ecosystem degradation (*less degraded*, *moderately degraded*, and *highly degraded*) and three categories of fisheries health status (*underexploited*, *fully exploited*, and *overexploited*). We collected information on the women's demographic and socioeconomic characteristics, household food insecurity, and consumption of food from different food groups by using a questionnaire. We estimated oyster consumption and nutrient intakes per day as the mean of the consumption or intakes from repeat 24-hour dietary recalls, and determined blood hemoglobin (Hb) concentration using a Hemocue photometer. Women's poverty level was estimated using the wealth-poverty score (WPS), which was calculated by assigning a value of 1 (yes) or 0 (no) to each of 10 items: household ownership of a: 1) canoe, 2) phone, 3) TV, 4) fan, 5) refrigerator, and 6) LPG stove; 7) main fuel used for cooking is liquified petroleum gas; 8) walls of house mainly made of cement; 9) consumption in the last month of corned beef; and 10) purchase of eggs in the last month. Total scores ranged from 0-10. WPS values were classified as high (richer household) if ≥ the site median value or low (poorer household) if < the site median value. We defined "any oyster consumption" as oyster consumption > 0 g in the repeat 24-hour dietary recalls, and any anemia as Hb < 12 g/dl. Across estuary sites within each country, we compared mean oyster consumption and nutrient intakes (including iron intake from oysters) per day, household food insecurity, percent of women achieving the MDD-W,

and anemia prevalence, using ANOVA (SAS PROC GLM) for continuous variables and logistic regression (SAS PROC LOGISTIC) for binary variables. Within country, we used Poisson regression models (SAS PROC GENMOD) to determine whether WPS level (high/low) and any oyster consumption were associated with each of the following outcomes: (a) household food insecurity, (b) MDD-W, and (c) anemia. In each Poisson regression model, we controlled for estuarine site and additional covariates that were significantly associated with the outcome at 0.2 alpha in correlation analysis. Finally, we determined the arsenic (As), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), cupper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), nickel (Ni), phosphorus (P), potassium (K), selenium (Se), sodium (Na), and zinc (Zn) contents of oysters collected from each of the three estuarine sites in Ghana (total n = 915), compared mean mineral concentrations across sites by ANOVA, and evaluated the potential health risks of exposure to heavy metals (As, Ca, Pb, and Hg) through oyster consumption among the women shellfishers. For all statistical analyses, the level of significance (α) was set at 0.05.

Results: In Ghana, 504 women were recruited from the Densu (*highly degraded* mangrove ecosystem and *underexploited* fisheries health status, n = 200), Narkwa (*moderately degraded* mangrove ecosystem and *overexploited* fisheries health status, n = 166), and Whin (*less degraded* mangrove ecosystem and *fully exploited* fisheries health status, n=138) estuary sites from June 8, 2021 to July 16, 2021. Mean ± SD age (32 ± 9 y) did not differ by site (P = 0.30). Mean ± SD WPS was higher among the Densu (5 ± 3) and Whin (5 ± 2) women than the Narkwa (3 ± 2) women (P < 0.001), and the percentage of households with high WPS (≥ 4) was greater for the Densu (63%) and Whin (65%) sites than the Narkwa (37%) site (P <0.001).

Across the three sites, there were no significant differences in mean total daily iron (P = 0.18) or zinc (P =0.14) intake. Only 13 percent of the women consumed any oyster (> 0 g) in the repeat 24-hr recalls, with the group percentages being significantly greater (P < 0.001) for the Densu (18.6 percent) and Narkwa (13.9 percent) sites than the Whin (1.4 percent) site. Mean ± SD oyster consumption (g/d) was significantly higher among the Densu (9.6 ± 26.0) and Narkwa (6.7 ± 25.7) women than the Whin (0.3 ± 2.2) women, (P = 0.001). Mean daily iron intake from oyster (mg) was significantly higher among the Densu (2.4 ± 6.5) and Narkwa (1.6 ± 5.4) women than the Whin (0.07 ± 0.55) women, (P < 0.001); mean daily zinc intake from oyster (mg) was significantly higher among the Densu (1.6 ± 4.3) and Narkwa (1.0 ± 3.5) women than the Whin (0.04 ± 0.36) women, (P < 0.001). The average percentage contribution of oyster consumption to iron intake amounted to 11-14 percent for the Densu and Narkwa women and only 0.3 percent for the Whin women, while the average percentage contribution of oyster consumption to zinc intake amounted to 14-18 percent for the Densu and Narkwa women and only 0.3 percent for the Whin women. Percentage of women with any household food insecurity did not differ by site (92 percent overall, P = 0.09), but the percentage with severe food insecurity was greater for the Narkwa site (85 percent) than the Densu site (72 percent), with the Whin site (79 percent) in between, (P = 0.012). Anemia prevalence (20 percent overall; P = 0.08) and the percentage of women who achieved the MDD-W (21 percent overall; P = 0.65) did not differ by site.

The multivariate Poisson regression models controlling for estuarine site and additional background factors associated with the outcome at 0.2 alpha level showed that WPS (high/low) related significantly (P = 0.021) in the opposite direction to household food insecurity, with 96 percent (95 percent CI: 93, 100) of women from richer households experiencing household food insecurity compared with 86 percent (95 percent CI: 79, 93) of women from poorer households. Apart from this, WPS (high/low) and any oyster consumption were not associated with household food insecurity, achievement of MDD-W, or anemia status.

The oysters collected from the three estuarine sites differed significantly in the mean concentrations of all the minerals and heavy metals measured. There was no consistent pattern of higher or lower mean macromineral (Ca, Mg, P, K, and Na) concentrations by estuarine site. Mean trace mineral (Cr, Co, Cu, Fe, Mn, Ni, Se, and Zn) and heavy metal (Ar, Cd, Pb, and Hg) concentrations were consistently higher in the Narkwa samples than those from other two sites. The mean ± SD heavy metal concentrations of oysters from across the three sites ranged from 0.043 ± 0.032 – 0.189 ± 0.167 for total As, 0.011 ± 0.008 – 0.047 ± 0.042 for i-As (estimated at an average of 25 percent of total arsenic), 0.023 ± 0.017– 0.065 ± 0.051 for Cd, 0.016 ± 0.022 – 0.057 ± 0.046 for Pb, and 0.022 ± 0.025 – 0.065 ± 0.132 for Hg. None of the oysters from the three sites exceeded the maximum concentration limits for As, Cd or Pb according to international guidelines; one sample from the Narkwa exceeded the maximum concentration limit for Hg only. A mean Hazard Index for oyster consumption among the women shellfishers ranged from 0.04 at the Whin site to 0.13 at the Narkwa site; none of the estuarine sites had a mean HI exceeding 1. At all three sites, the primary driver of the HI values among the women shellfishers was Hg accounting for 50-57 percent, followed by Pb accounting for 22 -29 percent, with Cd contributing the least (6-8 percent).

In The Gambia, 214 women were recruited from the Allahein (*highly degraded* mangrove ecosystem and *fully exploited* fisheries health status n = 35), Tanbi (*moderately degraded* mangrove ecosystem and *underexploited* fisheries health status, n = 109), and Bulock (*less degraded* mangrove ecosystem and *overexploited* fisheries health status, n = 70) estuary sites from July 2-23, 2021. Mean ± SD age (31 ± 9 y, P = 0.06) and wealth-poverty score (overall: 5 ± 2; P = 0.35) did not differ by site, and the percentage of households with high WPS (≥ 5) (overall: 62%; P = 0.46) was similar across sites.

Women across the three sites did not differ in mean total daily iron intake (P = 0.15), but differed in mean total daily zinc intake (P < 0.001), with the mean zinc intake values (mg/day) being significantly greater for the Allahein (10.1 ± 7.3) and Bulock (8.2 ± 4.9) sites than the Tanbi site (6.3 ± 3.3). Only 7 percent of women in The Gambia reportedly consumed any oyster (> 0 g) in the repeat 24-hr recalls, and the percentage did not differ significantly across sites (P = 0.58). Mean ± SD oyster consumption (1.9 ± 8.1 g/d, P = 0.74) and iron intake from oyster (0.06 ± 0.26 mg/d, P = 0.73) did not differ by site. Across the three sites, the average percentage contribution of oyster consumption to the women's iron intake amounted to 0.7-2.5 percent, while the average percentage contribution of oyster consumption to zinc intake amounted to 2.0-6.3 percent. The percentage of women with any food insecurity was greater for the Tanbi site (87 percent) than the Allahein site (66 percent), with the Bulock site (84 percet) in between and not significantly different from the other two sites (P = 0.018); the percentages of women with severe household insecurity (43 percent, P = 0.06), adequate dietary diversity (61 percent, P = 0.25), and anemia (41 percent; P = 0.55) were similar across sites.

The multivariate Poisson regression models controlling for estuarine site and additional background factors showed that the WPS level (high/low) related significantly (P = 0.001) in opposite direction to the achievement of MDD-W, with 43 percent (95 percent CI: 37, 51) of women from richer households achieving MDD-W compared with 62 percent (95 percent CI: 53, 73) of women from poorer households. Apart from this, WPS (high/low) and any oyster consumption were not associated with household food insecurity, achievement of MDD-W, or anemia status.

Conclusion and recommendations: Household poverty and oyster consumption were not associated with food insecurity, dietary diversity, or anemia among women shellfishers in Ghana and The Gambia. The low oyster consumption among the women shellfishers in both countries may have led to the lack of any substantial impact on these outcomes. The women shellfishers likely sell a much greater proportion of the oysters they harvest than they consume and have a diet that depends more on other aquatic animal source foods (e.g., small pelagic fishes). In both countries, the women shellfishers mostly remain poor, so there is also no association of the women's household poverty level with their household food security, dietary diversity, or anemia. Oysters offer a rich source of iron, zinc, and other nutrients not only for women shellfishers in Ghana, but also in The Gambia. Yet, oysters currently appear to be underutilized in the diet of women shellfishers in both countries. Promoting oyster consumption may be a promising strategy to increase nutrient intakes and prevent anemia in estuarine communities in Ghana and The Gambia. There should be regular monitoring of Hg and Pb contamination of oysters and other aquatic animal foods, especially at the Narkwa estuarine site. Further research is needed to: (a) explore how the women shellfishers in Ghana and The Gambia might use their shellfishery resources more effectively to prevent anemia, (b) investigate the possible reasons for the relatively high mean heavy metal concentrations of oysters from the Narkwa site in Ghana and their implications, and (c) assess the human health risk of heavy metal concentration of oysters from the estuarine sites in The Gambia, as done for those in Ghana.

1. INTRODUCTION

In West Africa, low dietary intake of iron is recognized as a major cause of anemia (Mwangi et al., 2017). Among the West African coastal countries, anemia prevalence in women of reproductive age ranges from 35% to 52% (World Health Organization (WHO), 2020). In Ghana, the national prevalence of anemia among women of child-bearing age was estimated at 42% in 2015; in the four coastal regions (Volta, Greater Accra, Central, and Western regions) the anemia prevalence ranged from 42% to 49% (GSS, 2015). In The Gambia, the national prevalence of anemia among women of child-bearing age was estimated at 44% in 2019-2020, with a wide variation across Local Government Areas, from 39% prevalence in Brikama Area to 62% prevalence in Kuntaur Area (GBoS and ICF, 2019).

A recent meta-analysis (Young et al., 2019) showed anemia during pregnancy was associated with an 84% increased risk of postpartum hemorrhage, a leading cause of maternal death in Africa. Maternal anemia is also a risk factor for poor birth outcomes including low birth weight, preterm birth, and neonatal mortality (Young et al., 2019). Reducing the prevalence of anemia in women of reproductive age is one of the WHO 2025 Global Nutrition Targets (WHO, 2014).

Coastal fisheries, including shellfish-harvesting, provide a rich source of nutrients for people living near the estuaries (Taylor, Roberts, Milligan, & Ncwadi, 2019), and shellfish are an excellent source of vitamins and minerals (USDA, 2020). Although the nutrient content of oysters in West Africa has not previously been measured, one serving (100 g) of raw U.S. eastern oysters provides 39.3 mg zinc and 4.6 mg iron (USDA, 2020), which meets 100% of the Recommended Dietary Allowance (RDA) for zinc (8 mg/d) and 26% of the RDA for iron (18 mg/d) for women of reproductive age (IOM, 2011). In comparison, one serving (100 g) of beef steak, widely recognized as a recommended source for iron and zinc, provides 10.1 mg zinc and 3.6 mg iron (USDA, 2020), which meets 100% of RDA for zinc and 20% of RDA for iron for women of reproductive age (IOM, 2011). As an affordable and accessible source of iron, shellfish could help reduce anemia among women of reproductive age living near estuary sites in West Africa.

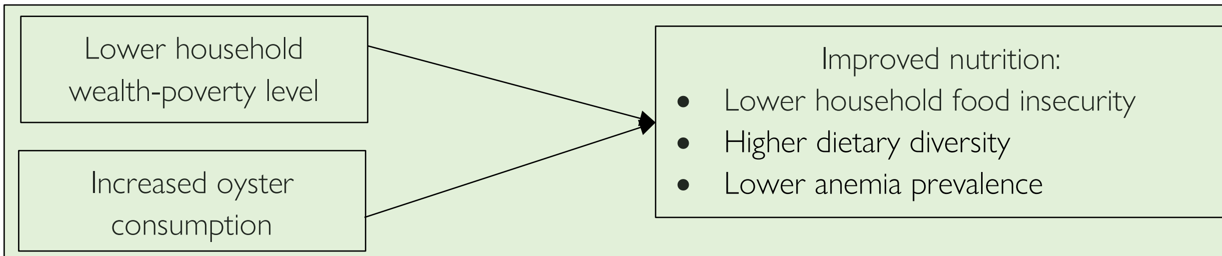
Shellfishing (the collection of oysters, cockles, and other mollusks) is a small-scale fishery practiced almost exclusively by women in estuarine ecosystems (Piñeiro-Antelo & Santos, 2021). Success at shellfishing depends on appropriate management of local shellfisheries resources, including the health of mangrove forests, which serve as attachment points for oysters, a natural barrier to moderate flooding from storms and sea level rise (Hutchison, Spalding, & zu Ermgassen, 2014), and a food reservoir for oysters and other species (Driver et al., 2012). However, West African mangroves have declined significantly during the last 25 years (E. O. Chuku, Abrokwah, et al., 2020), posing livelihood risks for communities that depend on them. Critical threats to mangrove ecosystems generally include sea level rise (Amuzu, Jallow, Kabo-Bah, & Yaffa, 2018), harvesting of wood for energy and construction materials (Crow & Carney, 2013), and land-use changes driven by coastal population growth (Kirui et al., 2013).

There is a concern that in estuarine communities where the local shellfisheries resources are poorly managed, there may be less availability and consumption of oysters, thereby denying such communities of potentially vital resource for income and the prevention of food insecurity, low dietary diversity, and anemia. In these circumstances, the women shellfishers who depend on the local shellfisheries resources for their livelihood are the ones most likely to be impacted. However, whether food insecurity, dietary diversity, and anemia are related to oyster consumption and household poverty level among women shellfishers in Ghana and The Gambia is unclear.

This study aimed to examine nutrition outcomes including food intake, food insecurity, dietary diversity, and anemia prevalence among women shellfishers 15-49 years of age (women of reproductive age) living at three estuary sites in Ghana and three estuary sites in The Gambia. We aimed to test the hypotheses that within country, lower poverty level and higher oyster consumption (such as resulting from increased oyster yields and availability due to improved management of shellfisheries resources) would be associated with (a) lower household food insecurity, (b) greater dietary diversity, and (c) lower prevalence of anemia. In addition, we aimed to determine the mineral and heavy metal concentrations of oysters collected from each of the three estuary sites in Ghana, and to evaluate whether heavy metal contamination is of concern to the health of women shellfishers at these sites.

Theory of Change

The theory of change for the study describes the interrelationship between household wealth-poverty level; oyster consumption; and household food security, women's dietary diversity, and anemia prevalence among women shellfishers in Ghana and The Gambia. The primary assumption of the Theory of Change is that higher household income level and oyster consumption (resulting from increases in oyster yields and availability due to improved management of shellfisheries resources) contributes to low household food insecurity, greater dietary diversity, and low prevalence of anemia (see Figure 1 below).



Theory of change. Among women shellfishers in Ghana and The Gambia, higher oyster consumption and household income (resulting from increased oyster yield and availability due to improved management of shellfisheries resources) would impact positively on the women's nutrition, including low household food security, greater dietary diversity, and lower anemia prevalence.

Figure 1: Theory of change regarding relationships of nutrition and anemia with oyster consumption and poverty among women shellfishers.

2. METHODS

2.1. Selection of study areas

The selection method of the three estuary sites in Ghana and the three estuary sites in The Gambia–which served as the study areas–has been reported previously (E. O. Chuku, Duguma, et al., 2020). Briefly, the sites were selected purposively within each country based mainly on the sites' (a) level of mangrove ecosystem degradation (i.e., less degraded, moderately degraded, and highly degraded), and (b) fisheries health status category (i.e., underexploited, overexploited, and fully overexploited). The other selection considerations were: (i) scale of existing shellfishery activities, (ii) level of involvement of women in shellfishery activities, (iii) scale of existing mangrove systems-based livelihoods, and (iv) changes in mangrove health condition over time.

First, a purposive sampling approach was used to identify candidate women shellfishing sites with significant variation in key outcome variables such as fisheries and mangrove health; and treatment variables such as governance, gender dimensions, and women's empowerment. The information needed to identify the candidate sites was derived from secondary sources, expert opinions, and local knowledge. Second, additional information on the candidate sites was collected through rapid field assessments. Lastly, the research team held discussions and decided, by a consensus, the final three estuary sites in each country.

Ghana

The three estuary sites selected were: the Densu Estuary (Greater Accra Region), the Ekumfi Narkwa Lagoon (Central Region), and the Whin Estuary (Western Region) (Figure 2).

Densu Estuary

The study was conducted at the Bortianor area, including the Tsokomey, and Tetegu communities in the Ga South Municipal District in the Greater Accra Region. The area covers about 5,892 ha of land, with an estimated population of 350,121 according to the 2021 population and housing census. The coastal mangrove area was estimated at approximately 206 ha in 2020 (E. O. Chuku, Duguma, et al., 2020). The main occupation there is fishing and fish processing–predominantly at a small scale level. The main shellfishing activity is oyster harvesting, with an estimated 150-200 women shellfishers. The livelihood activities connected to mangroves include culture-based fishing, firewood collection, and salt mining. The mangrove condition in the area is considered to be highly degraded because of factors such as mangrove-harvesting for fuel and settlement expansion. The fisheries health status of the area was categorized as underexploited based on the relatively low fishing mortality rate (0.07) and exploitation ratio (0.04) (Table 1).

The Densu estuary is a protected wetland declared as a Ramsar Site in 1992, but the enforcement of Ramsar Site regulations is weak. The Densu Delta Community-Based Fisheries Management Plan–which delegates exclusive use rights to the oyster fisheries resources to the Densu Oyster Pickers Association–was approved by the Ministry of Fisheries and Aquaculture Development (MOFAD) and the Fisheries Commission in December 2020 (MOFAD, 2020). Currently, the area operates a 5-month (November - April) oyster-harvesting closed season each year to allow the oyster population to replenish itself. The area is noted for fishing-dependent households with low dietary diversity (low consumption of "other vitamin A rich fruits and vegetables", "other fruits and vegetables", organ meat, meat and fish, legumes and nuts, and milk and milk products) and moderate-to-severe hunger, particularly in the period of the year when artisanal and inshore fishing is closed (E. O. Chuku, Duguma, et al., 2020).

Ekumfi Narkwa Lagoon

The main shellfishery community at this estuary site where the study was conducted was Ekumfi Narkwa in the Ekumfi District, with an estimated population of 56,741 according to the 2021 population and housing census. The coastal mangrove area was estimated at about 110 ha in 2020 (E. O. Chuku, Duguma, et al., 2020). The main shellfishing activity includes oyster, cockle, and shrimp harvesting. The livelihood activities connected to mangroves include staple-food (maize, cassava, plantain) farming and salt mining. The mangrove condition in the area is considered to be moderately degraded consisting of low-density naturally occurring mangroves. The key factors affecting mangroves are mangrove-harvesting for fuel, settlement expansion (land reclamation), and mangrove dieback due to factors including environmental pollution. The fisheries health status of the area was categorized as overexploited based on the relatively high fishing mortality rate (1.65) and exploitation ratio (0.5). The fishing system at the Ekumfi Narkwa site is open-access, and compliance with the customary law on no-fishing on Tuesdays is low. This area does not operate the oyster-harvesting open and closed seasons as does the Bortianor area, but access to oysters becomes more limited during the rainy season (May - October) because of increased difficulty with harvesting during the period. The Central Region, where Narkwa is located, is a known food insecure region of the country, with low average dietary diversity among children 6-59 months of age (E. O. Chuku, Duguma, et al., 2020).

Whin Estuary

The study was conducted at the New Amanful-Apremdo-Beahu area in the Ahanta West District (Western Region), with a population of about 153,140 according to the 2021 population and housing census. The coastal mangroves was estimated at approximately 178 ha in 2020 (E. O. Chuku, Duguma, et al., 2020). The main shellfishing activity includes oyster, shrimp, and periwinkle harvesting involving more than 80 women shellfishers. The livelihood activities connected to mangroves include firewood collection and a low level of bivalve shell trade. The mangrove condition in the area is considered to be less degraded/more stable. The fisheries health status of the area was categorized as fully exploited based on the fishing mortality rate of 0.8 and exploitation ratio of 0.29. The key factors affecting mangroves in the area are harvesting for fuel, settlement expansion (land reclamation), tourism, and mangrove dieback due to factors including pollution from sewage. The fishing system is open-access, and compliance with the customary law on no-fishing on Tuesdays is low. This area is also noted for fishing-dependent households with low dietary diversity and moderate-to-severe hunger in the period of the year when artisanal and inshore fishing is closed (E. O. Chuku, Duguma, et al., 2020).

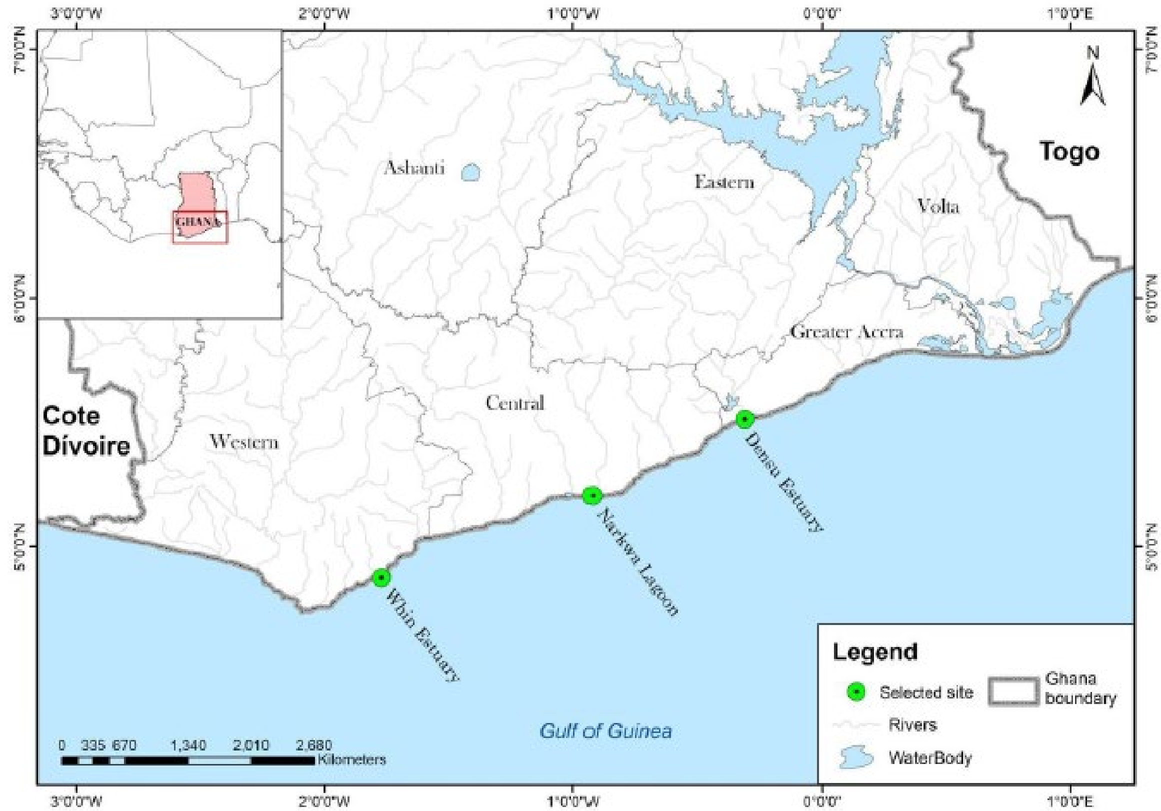


Figure 2: Estuary sites/Communities selected in Ghana (E. O. Chuku, Duguma, et al., 2020): Densu, Narkwa, and Whin.

The Gambia

The three estuary sites selected in The Gambia were the Allahein River estuary, the Bulock mangrove area, and the Tanbi Wetland area (Figure 3).

Allahein River Estuary

The study was conducted at the Berending and Kartong area. The mangrove area was estimated at about 424 ha in 2020 (E. O. Chuku, Duguma, et al., 2020).The main shellfishing activity is oyster harvesting, and over 100 women are involved. The livelihood activities connected to mangroves include firewood collection and vegetable gardening. The mangrove condition in the area is considered to be highly degraded. The fisheries health status of the area was categorized as fully exploited based on the fishing mortality rate of 0.59 and exploitation ratio of 0.28. The key factors affecting mangroves in the area are harvesting for fuel, settlement expansion (land reclamation), and dieback due to factors including pollution. Shellfishing groups exist but the governance structure may be weak (E. O. Chuku, Duguma, et al., 2020).

Tanbi Wetland

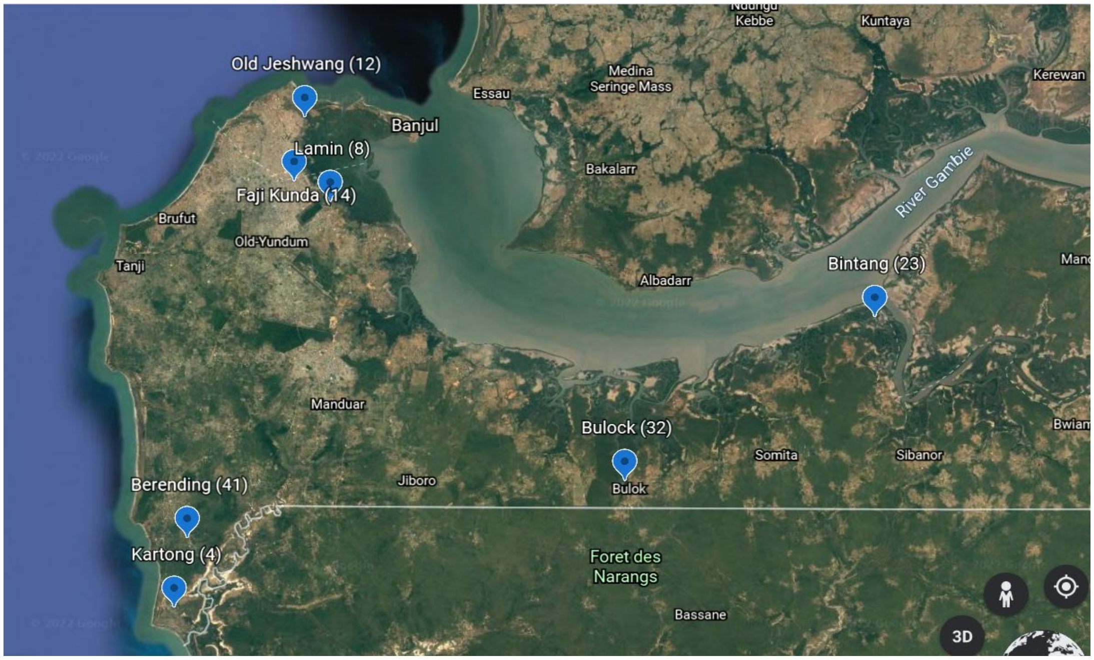
The study was conducted at the area which included Jeshwang, Abuko, Fajikunda, Kamalo, Lamin, Wencho, and Kubuneh. The mangrove area was estimated at approximately 2550 ha in 2020 (E. O. Chuku, Duguma, et al., 2020). The main shellfishing activity is oyster and cockle harvesting, with scores of women involved. The livelihood activities connected to mangroves include firewood collection, rice farming and vegetable gardening. The mangrove condition in the area is considered to be moderately degraded. The key factors affecting mangroves in the area are harvesting for fuel, settlement expansion (land reclamation), and dieback due to factors including pollution. The fisheries health status of the area was categorized as underexploited based on the fishing mortality rate of 0.04 and exploitation ratio of 0.05. The Tanbi area is a designated National Park and Ramsar site, but enforcement of Ramsar Site regulations is weak. In 2012, an Oyster and Cockle Shellfishery Co-management Plan for the Tanbi was approved and delegates use rights to the oyster and cockle fisheries to the TRY Oyster Women's Association (Republic of The Gambia, 2012).

Bulock mangrove area

The study was conducted at the Bulock and Bintang Bolong area. The coastal mangrove area was estimated at about 3539 ha in 2020 (E. O. Chuku, Duguma, et al., 2020). The main shellfishing activity includes oyster and cockle harvesting, with scores of women involved. The livelihood activities connected to mangroves include firewood collection, rice farming, and vegetable gardening. The mangrove condition in the area is considered to be less degraded. The key factors affecting mangroves in the area are harvesting for fuel, settlements expansion (land reclamation), and dieback due to factors including pollution. The fisheries health status of the area was categorized as overexploited based on the fishing mortality rate of 2.56 and exploitation ratio of 0.59. Local rules for harvesting shellfish are present.

Table 1: Fisheries Health Status of the study sites (Source: Chuku et al., 2020b).

Site	Fishing Mortality Rate	Exploitation ratio	Fisheries health
Densu	0.07	0.04	Underexploited
Narkwa	1.65	0.50	Overexploited
Whin	0.80	0.29	Fully exploited
Allahein	0.59	0.28	Fully exploited
Tanbi	0.04	0.05	Underexploited
Bulock	2.56	0.59	Overexploited



(Source: Google Map)

Figure 3: Estuary sites/Communities selected in The Gambia: Allahein, Tanbi and Bulock.

2.2. Study design and sampling

This was a cross-sectional study among non-pregnant women shellfishers of reproductive age (15-49 years) in three estuary sites in Ghana and three estuary sites in The Gambia. The study used a combination of random and snowballing sampling techniques to select women for the study. Where an estuary site had a women shellfishers' association, the leaders of the association were contacted for the list of their members, and the target sample size was selected randomly from the list if there were more women shellfishers on the list than the target sample size.

In Ghana, the Development Action Association provided the list of shellfishers' association members for the Densu estuary site. In The Gambia, the TRY Oyster Women's Association provided the list of shellfishers' association members for each of the three estuary sites. None of the lists received had more women than the target sample size, and therefore, the study team made efforts to contact all the women on each list. In addition, the team used the snowballing technique to identify other unlisted women shellfishers, with the aim of meeting the target sample size. For the two estuary sites in Ghana (Narkwa Lagoon and Whin Estuary) where no women shellfishers' association was identified, field workers used the snowballing technique to find women shellfishers for the study, often with assistance from opinion leaders and community members. Only one woman shellfisher per household was recruited into the study.

2.3. Data collection

On the day of recruitment, the study team collected women's information including demographic and socioeconomic characteristics, household food insecurity (Coates, Swindale, & Bilinsky, 2007; FAO, 2021), weight (Seca 874), height (Seca 217), and blood hemoglobin by finger-prick (HemoCue AG, Switzerland). The HemoCue device was calibrated daily using control cuvettes (Sigma Chemical Co., St. Louis, MO). The team conducted two non-consecutive 24-hour dietary recalls, the first on the day of recruitment and the second, within seven days after recruitment, by which we collected detailed data on the type of foods and quantities of foods the women shellfishers consumed.

In Ghana, the team collected oyster samples from each of the three estuary sites for the purpose of determining the mineral contents and heavy metal contamination. The sample size for the individual oyster samples (n = 305 per study site; total n = 915) was calculated using procedures described by the Food and Agriculture Organization (Greenfield & Southgate, 2003). At each study site, the team identified the main oyster harvesting locations and proportioned the 305 oysters per study site to the number of known harvesting locations at the site. At each oyster harvesting location, the team earmarked an estimated quadrat of 20 m^2 (Baggett, 2014) from where a local guide randomly collected the oysters. To ensure that the samples were representative from each study site, the team collected more samples from each oyster harvesting location than the number needed to meet the quota for the location. The samples from each location were mixed thoroughly before the quota sample was selected randomly. The oysters were shucked and the meat was extracted and hand-cleaned with a soft brush. The meat samples were weighed and packed individually in air-tight dispensing polystyrene bags, labelled, and transported on ice to the laboratory, where they were stored at -86 °C until analysis. Oyster samples were not collected in The Gambia.

The data collection was conducted from June 8, 2021 to July 16, 2021 (over 6 weeks), in Ghana and from July 2-23, 2021 (over 3 weeks) in The Gambia.

Phlebotomist measuring blood hemoglobin concentration in The Gambia

Field worker interviewing a woman shellfisher in The Gambia

Field worker administering a 24-hour dietary questionnaire in Ghana

Anthropometrists measuring height in Ghana

Figure 4: Data collection in Ghana and The Gambia.

2.4. Ethics approval

In Ghana, ethics approval for the study was obtained from the Ghana Health Service Ethics Review Committee. In The Gambia, ethics approval was obtained from The Gambia Government/Medical Research Council and The Gambia Joint Ethics Committee. Informed consent was obtained from all women who participated in the study.

2.5. Laboratory analysis of oyster samples

Digestion of Oyster Samples

The full muscle tissue of each oyster sample was digested in a mixture of 10 ml HNO_3 and 5 ml H_2SO_4 and heated on a hot plate at 95^0C for 1-3 hours. The sample was cooled to room temperature, 2 ml of 30% H_2O_2 was added, and it was reheated for 20 minutes. The mineralized sample was topped up with distilled water to 100 ml before reading the mineral content. The minerals and heavy metals measured were arsenic (As), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), nickel (Ni), phosphorus (P), potassium (K), selenium (Se), sodium (Na), and zinc (Zn).

Determination of Phosphorus Concentration

After mineralization, 1 ml of sample was diluted to 50 ml by the addition of a few drops of p-nitrophenol NH_4OH, 5 ml of a mixture of ascorbic acid and reagent A [$(NH_4)_6Mo_7O_{24}$, H_2SO_4 and $K_2Sb_2(C_4H_2O_6)_2$], and distilled water (Cho & Nielsen, 2017; Nielsen, 2017). Total phosphorus was determined using Spectroquant Pharo 300 UV-visible spectrophotometer (Chew et al., 2018; Jastrzębska, 2009). Phosphorus content in each sample was calculated as:

$$Phosphorus\ Content\ \ mg/kg\ = \frac{(Sampling\ reading - Blank\ reading)\ x\ Volume\ of\ extract}{weight\ of\ oyster\ x\ Volume\ of\ aliquot}$$

Determination of Other Minerals and Heavy Metals Concentrations

The concentrations of other minerals besides P were determined using Atomic Absorption Spectrometry (PinAAcle 900T Perkin Elmer, KY, USA). Most of the metals (including Ca, Mg, K, Na, Cr, Co, Cu, Fe, Mn, Ni, Se, Zn, Cd, and Pb) were determined by flow injection analysis-flame atomic absorption spectrometry using air-acetylene. As (Hydride Generation Technique) and Hg (Cold Vapour Technique) were measured using argon gas as fuel (Agemian, Sturtevant, & Austen, 1980; Edgell, 1989). Mineral and heavy metal concentrations were then calculated as:

$$Concentration\ of\ metal = \frac{concentration\ in\ extract\ (\mu g/ml)\ x\ volume\ of\ extract(ml)}{Weight\ of\ oyster\ sample\ (g)}$$

2.6. Heavy metal contaminants in oyster samples

The team evaluated the concentrations of 4 heavy metals (As, Cd, Pd, and Hg) in the oyster samples by calculating the percentage of oyster samples which had concentrations above the maximum concentration limit per kg of oyster meat according to international regulatory guidelines (**Table 2**).

Table 2: International regulatory limits for selected heavy metals in oysters.

Heavy metal	International regulatory limit
Arsenic (inorganic)	1.0 mg/kg wet weight
Cadmium	1.0 mg/kg wet weight
Lead	1.5 mg/kg wet weight
Mercury	1.0 mg/kg wet weight

Source: (EU/FAO, 2006; Montojo et al., 2021; Romero-Estévez et al., 2020; Wang & Lu, 2017); inorganic arsenic was based on Food Standards Australia and New Zealand guidelines (FSANZ, 2020).

Because As is toxic to human health in its inorganic form (Bjorklund, Tippairote, Rahaman, & Aaseth, 2020), the team estimated the average percent inorganic As (i-As) in the oyster samples using a conservative 25 percent of the total As (Lorenzana, Yeow, Colman, Chappell, & Choudhury, 2009) before calculating the percentage of oyster samples which had i-As concentrations above the maximum 1.0 mg/kg oyster meat set by the Food Standards Australia and New Zealand (FSANZ, 2020). The team used the European Union/Food and Agriculture Organization's maximum concentration limits per kg wet weight of oyster meat for Cd (1.0 mg), Pb (1.5 mg), and Hg (1.0 mg) (EU/FAO, 2006; Montojo et al., 2021; Romero-Estévez et al., 2020; Wang & Lu, 2017)..

2.7. Human health risk assessments of heavy metal concentrations of oysters

The team evaluated the potential health risks of heavy metal exposure (**i-As**, Cd, Pb, and Hg) from oyster consumption among the women shellfishers based on the Estimated Daily Intake (EDI) of metals, Target Hazard Quotient (THQ), and Hazard Index (HI) (Bristy et al., 2021; Joseph, Iwok, & Ekanem, 2021). The EDI (amount of the heavy metal in oysters expressed as mg/kg body weight/day which can be ingested daily over a lifetime without appreciable health risk) for each metal was calculated using metal concentration (C) from oysters (mg/kg wet weight), the average daily oyster consumption, ADC (kg) of the women shellfishers, and the average body weight (ABW) of women shellfishers (kg) (Bristy et al., 2021; Yap et al., 2020):

$$Estimated\ Daily\ Intake, EDI\ = \frac{Metal\ conc\ in\ oyster\ x\ Av.daily\ oyster\ consumption}{Av.body\ weight\ of\ women\ shellfishers}$$

The team estimated the average daily oyster consumption of the women from the repeat 24-hr recalls as the overall mean oyster consumption across the three estuary sites, which was equivalent to 0.006 kg/person/d. The team used the overall daily mean oyster consumption in this calculation (instead of site-specific values), given that the daily oyster consumption among the women at the three sites differed only between the Densu and Whin sites, but not between the Densu and Narkwa or Narkwa and Whin sites. The team could not use the median value of the daily oyster consumption because this value was zero. The average body weight of the women shellfishers was based on the 50^{th} percentile (median) of the overall weight distribution of women shellfishers across the three sites, which was 61 kg.

The THQ method estimates the health risk based on non-carcinogenic effects (Bristy et al., 2021) and is expressed as the ratio of EDI (exposure) to the oral reference dose (RfD) (Joseph et al., 2021).

$$Target\ Hazard\ Quotient, THQ = \frac{Metal\ conc. in\ oyster\ x\ Av. daily\ oyster\ consumption}{Av. body\ weigh\ of\ women\ shellfishers\ x\ RfD}$$

or:

$$Target\ Hazard\ Quotient, THQ = \frac{EDI}{RfD}$$

The RfD is the oral daily exposure (mg/kg/day) which will not result in health issues in the course of a lifetime (Joseph et al., 2021). The RfD values used (Moslen & Miebaka, 2017; USEPA, 2018) were shown in Table 3.

Table 3: RfD values for selected metals.

Heavy metal	Reference Dose (RfD) values, mg/kg/day
Arsenic (inorganic)	0.0003
Cadmium	0.001
Lead[1, 2]	0.0002
Mercury[1]	0.0001

[1]RfD values for lead (Lim, Aris, & Zakaria, 2012) and mercury (Holloman & Newman, 2012) were not available from the IRIS (USEPA, 2018); [2]The RfD for lead was based on a reference value of 12.5 µg/day (FDA, 2018; Wong, Roberts, & Saab, 2022) for women of reproductive age with average weight of 61 kg)

A THQ value <1 indicates the level of exposure to metal contamination is smaller than the oral reference dose, and therefore, it is negligible or not likely to cause any deleterious effects during lifetime in human population (Chien et al., 2002).

We calculated the HI as the sum of the individual THQ of i-As, Cd, Pb, and Hg of the oyster samples (Antoine, Fung, & Grant, 2017; Joseph et al., 2021; Vieira et al., 2021):

$$HI = THQ_{inorganic\ arsenic} + THQ_{cadmium} + THQ_{lead} + THQ_{mercury}$$

The Hazard Index assesses the cumulative potential health risk posed by the four metals related to the average consumption and body weight of the women shellfishers in the study. The HI calculation assumed that oyster consumption would result in simultaneous exposure As, Cd, Pb, and

Hg. HI >1 indicates a potential for adverse non-carcinogenic health effects from oyster consumption. Even if the THQ values were < 1 individually, the simultaneous exposure to the 4 heavy metals from oyster consumption may result in adverse health effects (Antoine et al., 2017).

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2.8. Dependent variables

The three primary dependent variables in this study were: (a) household food insecurity (yes/no), (b) achievement of MDD-W (yes/no), and (c) any anemia status (yes/no).

Secondary dependent variables were (i) oyster consumption and nutrient (including iron and zinc) intakes from the repeat 24-hour dietary recall; (ii) mild, moderate, and severe food insecurity at the time of enrollment; (iii) percentages of women who consumed food from different food groups and mean food group dietary diversity score at enrolment; (iv) hemoglobin concentration and mild, moderate and severe anemia status at enrollment; (v) minerals and heavy metal concentrations of oysters collected from three estuary sites in Ghana; and (vi) EDI, THQ, and HI of heavy metals in the oysters collected in Ghana.

Women's nutrient intakes from the 24 hour recalls were analyzed based on a food composition table from a previous study in Ghana (Lartey et al., 2014), which we supplemented with data from the West African Food Composition Table (FAO, June, 2012) and the United States Department of Agriculture Nutrient Database (USDA, February, 2011). For the iron and zinc contents of oyster, the team used the average values obtained from the mineral analysis of the 900+ oyster samples collected from across the three estuarine site in Ghana, which are reported herein. Women's daily dietary intake of oysters and specific nutrients was estimated as the mean of the intakes from the two dietary recalls (Zhou et al., 2021). The team defined "any oyster consumption" as a mean oyster consumption greater than 0 g in the two dietary recalls. Household food insecurity was assessed using the Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2007). This scale measures the HFIAS score, which is a continuous measure of the degree of food insecurity (access) in the household in the past four weeks calculated by summing the codes for each frequency-of-occurrence question. The score ranges from 0 to 27 and women are categorized into mild, moderate, and severe food insecurity, with a higher score meaning more food insecurity experience by the household. The team created the binary variable "household food insecurity" (yes/no) by combining mild, moderate, and severe food insecurity.

Women's consumption of food from different food groups, 10-food group dietary diversity score (DDS), and minimum dietary diversity for women (MDD-W: DDS ≥ 5) were determined based on the first 24 hour recall conducted on the day of enrolment using procedures described by the FAO (FAO, 2021). The 10-food groups were: (i) Grains/roots/tubers, (ii) Pulses, (iii) Nuts/seeds, (iv) Milk/milk products, (v) Meat/poult/fish, (vi) Eggs, (vii) Dark green leafy vegetables, (viii) Other vitamin A-rich fruits and vegetables, (ix) Other vegetables, and (x) Other fruits (FAO, 2021). Any anemia was defined as hemoglobin, Hb < 12 g/dl, mild anemia as Hb 10.0-11.9 g/dl, moderate anemia as Hb 7.0-9.9 g/dl, and severe anemia Hb < 7 g/d (GSS/GHS/ICF, 2015).

2.9. Independent variables and covariates

The two independent variables which were investigated in this study were (a) the wealth-poverty score (WPS) level (high or low), and (b) any oyster consumption. First, we created the WPS for each woman by assigning a value of 1 (yes) or 0 (no) to each of 10 items, including some items used for the Poverty Probability Index for Ghana (IPA, 2017), namely: (i) purchased any chicken eggs (fresh or single) in past month, (ii) purchased any raw or corned beef in past month, (iii) main construction material used for the outer wall of house is cement, (iv) main fuel used by the household for cooking is LPG, (v) any household member owns a gas stove, (vi) any household member owns a refrigerator, (vii) any household member owns a fan, (viii) any household member owns a television, (ix) any household member owns a mobile phone, and (x) any household member owns a canoe. The scores were summed to give a total score of 0 – 10. No score was calculated if any of the 10 summative variables was missing. A higher wealth-poverty score indicated a richer household. Next, we used each country's median WPS value as the cut-off for defining "high" or "low" WPS. Thus, WPS values were classified as high if ≥ the country median value and low (poorer household) if < the country median value. We defined "any oyster consumption" as the mean oyster consumption greater than 0 g in the two dietary recalls

Within country, we considered estuarine site as the main covariate in the multivariable analysis of the association of wealth-poverty score (WPS) level and any oyster consumption with each of the primary outcomes (household food insecurity, achievement of MDD-W, and any anemia status). Additional covariates for each multivariable model were derived from a list of 35 potential covariates–only those variables that showed statistically significant association with the dependent variable at 0.2 alpha level in correlation analysis (SAS PROC CORR) were included in the final model.

2.10. Sample size and data analysis

The sample size for the women shellfishers within each country was based on detecting a Cohen's moderate effect size *d* of 0.3 in mean blood hemoglobin concentration between any pair of the three estuary sites with a two-sided 5 percent test and 80 percent power. This gave an estimated target sample of 200 participants per site and 600 for each country.

We performed all statistical analyses using SAS for Windows version 9.4 (Cary, NC). Within country, women's background socio-demographic characteristics were summarized by estuary site as mean ± SD for continuous variables, or number of participants and percentages for categorical variables. The primary and secondary dependent variables were compared across the three estuary sites in each country by using ANOVA (SAS PROC GLM) for continuous variables and logistic regression (SAS PROC LOGISTIC) for binary variables. One participant with an extremely large mean daily oyster consumption (> 400 g/day) in the Ghana sample was excluded from the analysis of daily oyster and nutrient intakes to avoid the possible distorting-effect of an outlier observation.

In multivariate analyses, we used Poisson regression (SAS PROC GENMOD) (Spiegelman & Hertzmark, 2005) to determine the association of household wealth-poverty level and any oyster consumption–whether (a) household food insecurity, (b) achievement of MDD-W, and (c) anemia prevalence–in Ghana and The Gambia, when controlling for estuarine site and additional covariates significantly associated with the outcome at alpha of 0.2 in correlation analysis (SAS PROC CORR). Finally, we compared the mean mineral concentrations of oysters from the three estuary sites in Ghana by using ANOVA, and evaluated the potential health risks of heavy metal (cadmium, lead, and mercury) consumption from oysters among the women shellfishers.

For the analysis of all variables, the level of significance (α) was set at 0.05.

3. RESULTS

In total, 504 women shellfishers were recruited from the three estuary sites in Ghana, including 200 from the Densu estuary (Bortianor, Tsokomey, and Tetegu communities), 166 from the Narkwa Lagoon (Ekumfi Narkwa), and 138 from the Whin estuary (New Amanful, Apremdo, and Beaho communities). These women comprised nearly all women shellfishers in the target age group (women of reproductive age) available for enrollment at the three sites.

In The Gambia, the number of women shellfishers in the target age group available for recruitment at each of the three sites was much smaller than in Ghana. In all, 214 women shellfishers were recruited, including 35 from the Allahein River estuary, 109 from the Tanbi Wetland (including Oyster Creek), and 70 from the Bulock mangrove area (including Bintang Bolong).

3.1. Demographic and socioeconomic characteristics of women shellfishers

The summary results of the women's demographic and socioeconomic characteristics are presented in **Table 4** for Ghana, and **Table 5** for The Gambia. In Ghana, the mean ± SD age of women in the overall sample was 32 ± 9 years. Out of the 21 demographic and socioeconomic status variables listed in Table 4, women shellfishers across the three estuary sites differed significantly in 17 variables. In general, the women at the Densu and Whin estuary sites had more years of schooling and had indicators of a higher socioeconomic status (e.g., more women living in households possessing various household items). Mean ± SD WPS was significantly greater among the Densu (5 ± 3) and Whin (5 ± 2) women than the Narkwa (3 ± 2) women ($P < 0.001$). Similarly, the percentage of women from households with high WPS was greater for the Densu (63 percent) and Whin (65 percent) sites than the Narkwa (37 percent) site ($P < 0.001$).

In The Gambia, the mean ± SD age of women in the overall sample was 31 ± 9 years. Out of the 21 demographic and socioeconomic status variables measured, the women shellfishers differed by estuary site in 11 variables. In general, women at the three sites in The Gambia appeared to be more similar to each other than those in Ghana. Mean ± SD WPS (overall: 5 ± 2; $P = 0.35$) and the percentage of households with high WPS (≥ 5) (overall: 62 percent; $P = 0.46$) did not differ by site.

Table 4: Demographic and socioeconomic characteristics of women shellfishers 15-49 years of age who participated in the study, by estuary site, in Ghana[1].

	Estuary sites in Ghana				
	Densu	Narkwa	Whin	P[2]	Total
Age, y	32 ± 9 (200)	31± 10 (166)	32 ± 10 (138)	0.30	33 ± 9 [504]
Ever attended school	162/200 (81.0)[a]	93/166 (56.0)[b]	98/137 (71.5)[a]	<0.001	353/504 (70.0)
Total years of schooling	6 ± 4 (200)[a]	3 ± 4 (166)[b]	6 ± 4 (138)[a]	<.0001	4.9 ± 4.0 [504]
Able to read (literacy)	70/162 (43.2)	37/92 (40.2)	53/97 (54.6)	0.10	160/351 (45.6)
Woman is married	99/200 (49.5)[b]	108/166 (65.1)[a]	61/138 (44.2)[b]	<0.001	268/504 (53.2)
Worked in the last 7 days	121/200 (60.5)[a]	62/166 (37.3)[b]	89/138 (64.5)[a]	<0.001	272/504 (54.0)
Number of household members	6 ± 2 (200)[b]	7 ± 2 (166)[a]	7 ± 3 (138)[a]	<0.001	6 ± 3 [504]
Purchased eggs past month	156/200 (78.0)[a]	96/166 (57.8)[b]	97/138 (70.3)[ba]	0.0002	349/504 (69.2)
Purchased corned beef past month	111/200 (55.5)[a]	58/166 (34.9)[b]	68/138 (49.3)[a]	<0.001	237/504 (47.0)
House outer wall made with cement	115/198 (58.1)[b]	134/165 (81.2)[a]	112/138 (81.2)[a]	<.0001	361/501 (72.1)
Main fuel for cooking is wood	12/200 (6.0)[b]	44/165 (26.7)[a]	30/138 (21.7)[a]	<.0001	86/503 (17.1)
Main fuel for cooking is charcoal	136/200 (68.0)	114/165 (69.1)	90/138 (65.2)	0.76	340/503 (67.6)
Main fuel for cooking is LPG	52/200 (26.0)[a]	7/165 (4.2)[c]	18/138 (13.0)[b]	<0.001	77/503 (15.3)
Household member owns gas stove	104/200 (52.0)[a]	20/166 (12.0)[c]	45/138 (32.6)[b]	<0.001	160/503 (31.8)
Household member owns fridge	52/200 (26.0)[a]	25/166 (15.1)[b]	44/138 (31.9)[a]	0.003	121/504 (24.0)
Household member owns fan	98/200 (49.0)[a]	39/166 (23.5)[b]	66/138 (47.8)[a]	<0.001	203/504 (40.3)
Household member owns TV	110/200 (55.0)[a]	59/166 (35.5)[b]	86/138 (62.3)[a]	<0.001	255/504 (50.6)
Household member owns phone	102/200 (51.0)[a]	50/166 (30.1)[b]	67/138 (48.6)[a]	<0.001	219/504 (43.5)
Household member owns canoe	20/200 (10.0)	20/166 (12.0)	13/138 (9.4)	0.72	53/504 (10.5)
Wealth-poverty score (WPS)[3]	5 ± 3 (198)[a]	3 ± 2 (165)[b]	5 ± 2 (138)[a]	<0.001	4.1 ± 2.4 [501]
High WPS[4]	124/198 (62.6)[a]	61/165 (37.0)[b]	89/138 (64.5)[a]	<.0001	274/501 (54.7)

[1]Within country, values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.

[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.

[3]Wealth-poverty score for individual women were calculated as an adaptation of the procedure described by the Innovations for Poverty Action (IPA, 2017) by assigning a value of 1 (yes) or 0 (no) to each of 10 items and summing the scores to give the total score which ranged 0-10. A higher WPS indicates higher socioeconomic status.

[4]WPS values ≥ the country median value were classified as high (richer households). Median WPS was 4 for Ghana.

Table 5: Demographic and socioeconomic characteristics of women shellfishers 15-49 years of age who participated in the study, by estuary site, in The Gambia[1].

	Estuary sites in The Gambia				
	Allahein	Bulock	Tanbi	P[2]	Total
Age, y	34 ± 8 (35)	30 ± 9 (70)	32 ± 10 (105)	0.06	31 ± 9 [210]
Ever attended school	17/35 (48.6)	47/70 (67.1)	64/109 (58.7)	0.18	128/214 (59.8)
Total years of schooling	3.7 ± 4.3 (35)	5.9 ± 4.9 (70)	5.4 ± 5.4 (109)	0.20	5.3 ± 5.1 [214]
Able to read (literacy)	3/17 (17.6)[b]	22/46 (47.8)[ba]	36/64 (56.3)a	0.03	61/127 (48.0)
Woman is married	28/35 (80.0)[a]	50/70 (71.4)a	46/109 (42.2)[b]	<0.001	124/214 (57.9)
Worked in the last 7 days	32/35 (91.4)[a]	45/70 (64.3)[b]	65/109 (59.6)[b]	0.008	142/214 (66.4)
Number of household members	12 ± 6 (35)[ba]	15 ± 9 (70)[a]	10 ± 5 (109)[b]	<0.001	11 ± 7 [214]
Purchased eggs past month	25/35 (71.4)	43/70 (61.4)	83/109 (76.1)	0.11	151/214 (70.6)
Purchased corned beef past month	23/35 (65.7)	39/70 (55.7)	73/109 (67.0)	0.30	135/214 (63.1)
House outer wall made with cement	14/35 (40.0)[b]	23/70 (32.9)[b]	69/109 (63.3)[a]	<0.001	106/214 (49.5)
Main fuel for cooking is wood	31/35 (88.6)[a]	69/70 (98.6)[a]	66/109 (60.6)[b]	<0.001	166/214 (77.6)
Main fuel for cooking is charcoal	4/35 (11.4)[b]	1/70 (1.4)[b]	42/109 (38.5)[a]	<0.001	47/214 (22.0)
Main fuel for cooking is LPG	0	0	1/109 (0.9)	1.00	1/214 (0.5)
Household member owns gas stove	17/35 (48.6)[a]	16/70 (22.9)[b]	39/109 (35.8)[ba]	0.028	72/214 (33.6)
Household member owns fridge	17/35 (48.6[ba]	43/70 (61.4)[a]	45/109 (41.3)[b]	0.033	105/214 (49.1)
Household member owns fan	19/35 (54.3)	39/70 (55.7)	43/109 (39.4)	0.07	101/214 (47.2)
Household member owns TV	25/35 (71.4)[ba]	51/70 (72.9)[a]	59/109 (54.1)[b]	0.023	135/214 (63.1)
Household member owns phone	34/35 (97.1)	65/70 (92.9)	100/109 (91.7)	0.58	199/214 (93.0)
Household member owns canoe	3/35 (8.6)[b]	19/70 (27.1)[b]	65/109 (59.6)[a]	<0.001	87/214 (40.7)
Wealth-poverty score (WPS)[3]	5.1 ± 2.1 (35)	4.8 ± 2.2 (70)	5.3 ± 2.0 (109)	0.35	5.1 ± 2.1 [214]
High WPS[4]	25/35 (71.4)	65/109 (59.6)	43/70 (61.4)	0.46	133/214 (62.1)

[1]Values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.
[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.
[3]Wealth-poverty score for individual women were calculated as an adaptation of the procedure described by the Innovations for Poverty Action (IPA, 2017) by assigning a value of 1 (yes) or 0 (no) to each of 10 items and summing the scores to give the total score which ranged 0-10. A higher WPS indicates higher socioeconomic status.
[4]WPS values ≥ the country median value were classified as high (richer households). Median WPS was 5 for The Gambia.

3.2. Nutrient intakes, oyster consumption, and household food insecurity

The summary results of the total iron and zinc intakes (mg), oyster consumption (g), percent iron and zinc contribution from oysters, and household food insecurity of women shellfishers in Ghana and The Gambia are presented in **Table 6** and **Table 7**, respectively.

Total iron and zinc intakes, oyster consumption, and iron zinc intakes from oyster

In Ghana, women shellifishers across the three sites did not differ in mean total daily iron (P = 0.18) or zinc (P =0.14) intake. Overall, only 12.5 percent of the women consumed any oyster in the repeat

24-hour dietary recalls, with the group percentages being significantly greater (P < 0.001) for the Densu (18.6%) and Narkwa sites (13.9 percent) than the Whin site (1.4%). Mean ± SD daily oyster consumption (g) was significantly higher among the Densu (9.6 ± 26.0) and Narkwa women (6.7 ± 25.7) than the Whin women (0.3 ± 2.2) (P = 0.001). Mean daily iron intake from oyster (mg) was significantly higher among the Densu (2.4 ± 6.5) and Narkwa (1.6 ± 5.4) women than the Whin women (0.07 ± 0.55), (P < 0.001); likewise, mean daily zinc intake from oyster (mg) was significantly higher among the Densu (1.6 ± 4.3) and Narkwa (1.0 ± 3.5) women than the Whin women (0.04 ± 0.36), (P < 0.001). The average percentage contribution of oyster consumption to iron intake amounted to 11-14 percent for the Densu and Narkwa women and only 0.3 percent for the Whin women, while the average percentage contribution of oyster consumption to zinc intake amounted to 14-18 percent for the Densu and Narkwa women and only 0.3 percent for the Whin women.

In The Gambia, women shellifishers across the three sites did not differ in mean total daily iron intake (P = 0.15), but differed in mean total daily zinc intake (P < 0.001), with the mean zinc intake values (mg/day) being significantly greater for the Allahein (10.1 ± 7.3) and Bulock (8.2 ± 4.9) sites than the Tanbi site (6.3 ± 3.3). Overall, only 7 percent of women reported any oyster consumption and the percentage did not differ significantly across sites (P = 0.58). There was no difference in mean ± SD total oyster consumption (P = 0.74), which ranged (g) from 1.0 ± 5.7 at the Allahein site to 2.2 ± 8.9 at the Tanbi site. The women at the three sites also did not differ significantly in mean daily iron (P = 0.73) and zinc (P = 0.74) intakes from oyster. Across the three sites, the average percentage contribution of oyster consumption to the women's iron intake amounted to 0.7-2.5 percent, while the average percentage contribution of oyster consumption to zinc intake amounted to 2.0-6.3 percent.

Household food insecurity

Women shellfishers at the three sites in Ghana did not differ in percentage of women who were food secure, but a vast majority of them (between 72 percent at the Densu site and 85 percent at the Narkwa site) reported severe food insecurity. The women at Narkwa had a significantly higher mean ± SD HFIAS score (12.8 ± 6.5) than those at the Whin site (10.7 ± 6.6), but not compared to those at the Densu site (11.7 ± 5.9), P = 0.017.

In The Gambia, the percent of women who were food secure was significantly greater for Allahein (34%) than Tanbi (13 percent), but not Bulock (16 percent), P = 0.018. The percentage of women who reported severe food insecurity ranged from 26 percent at the Allahein site to 41 percent at the Bulock site to 49 percent at the Tanbi sites, and these did not differ significantly among the sites (P = 0.06). Women at the three sites did not differ significantly according to mean ± SD HFIAS score (P = 0.06).

Table 6: Total iron and zinc intakes, oyster consumption, percent iron and zinc contribution from oyster, and household food insecurity among women shellfishers 15-49 years of age who participated in the study, by estuary site, in Ghana[1].

	Estuary sites in Ghana				
	Densu	Narkwa	Whin	P[2]	Total
Total iron intake, mg	17.4 ± 11.0 (199)	14.6 ± 8.4 (166)	26.7 ± 110 (138)	0.18	19.0 ± 58.2 (503)
Total zinc intake, mg	8.7 ± 6.8 (199)	7.3 ± 4.8 (166)	12.7 ± 45.8 (138)	0.14	9.3 ± 24.6 (503)
Total oyster consumed, g	9.6 ± 26.0 (199)[a]	6.7 ± 25.7 (166)[a]	0.3 ± 2.2 (138)[b]	0.001	6.1 ± 22.4 [503]
Any oyster consumption[3]	37/199 (18.6)[a]	23/166 (13.9)[a]	2/138 (1.4)[b]	<0.001	62/503 (12.5)
Iron intake from oyster, mg	2.4 ± 6.5 (199)[a]	1.6 ± 5.4 (166)[a]	0.07 ± 0.55 (138)[b]	<0.001	1.5 ± 5.2 (503)
Zinc intake from oyster, mg	1.6 ± 4.3 (199)[a]	1.0 ± 3.5 (166)[a]	0.04 ± 0.36 (138)[b]	<0.001	1.0 ± 3.4 (503)
HFIAS score[4]	11.7 ± 5.9 (200)[ba]	12.8 ± 6.5 (166)[a]	10.7 ± 6.6 (138)[b]	0.017	11.8 ± 6.3 [504]
Food secure[4]	13/200 (6.5)	10/166 (6.0)	17/138 (12.3)	0.09	40/504 (7.9)
Food insecure[4]	187/200 (93.5)	156/166 (94.0)	121/138 (87.7)	0.09	464/504 (92.1)
Mildly food insecure[4]	20/200 (10.0)[a]	3/166 (1.8)[b]	4/138 (2.9)[b]	0.003	27/504 (5.4)
Moderately food insecure[4]	23/200 (11.5)	12/166 (7.2)	8/138 (5.8)	0.147	43/504 (8.5)
Severely food insecure[4]	144/200 (72.0)[b]	141/166 (84.9)[a]	109/138 (79.0)[ba]	0.012	394/504 (78.2)

[1]Values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.
[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.
[3]Any oyster consumption was defined as oyster consumption > 0 g in the repeat 24-hour dietary recalls.
[4]Household food insecurity was assessed using the Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2007). "Food insecure" households include mildly food insecure, moderately food insecure, and severely food insecure households.

Table 7: Total iron and zinc intakes, oyster consumption, percent iron and zinc contribution from oyster, and household food insecurity among women shellfishers 15-49 years of age who participated in the study, by estuary site, in The Gambia[1] .

	Estuary sites in The Gambia				
	Allahein	Bulock	Tanbi	P[2]	Total
Total iron intake, mg	27.0 ± 31.8 (35)	29.1 ± 46.2 (70)	19.8 ± 18.3 (109)	0.15	24.0 ± 32.3 [214]
Total zinc intake, mg	10.1 ± 7.3 (35)[a]	8.2 ± 4.9 (70)[a]	6.3 ± 3.3 (109)[b]	< 0.001	7.6 ± 4.9 [214]
Total oyster consumed, g	1.0 ± 5.7 (35)	2.0 ± 7.9 (70)	2.2 ± 8.9 (109)	0.74	1.9 ± 8.1 [214]
Any oyster consumption[3]	1/35 (2.9)	5/70 (7.1)	9/109 (8.3)	0.58	15/214 (7.0)
Iron intake from oyster, mg	0.2 ± 1.4 (35)	0.5 ± 2.0 (70)	0.5 ± 2.2 (109)	0.74	0.5 ± 2.0 [214]
Zinc intake from oyster, mg	0.2 ± 0.9 (35)	0.3 ± 1.3 (70)	0.4 ± 1.5 (109)	0.74	0.3 ± 1.3 [214]
HFIAS score[4]	4.0 ± 4.1 (35)	6.1 ± 5.2 (70)	6.3 ± 5.3 (109)	0.06	5.8 ± 5.1 [214]
Food secure[4]	12/35 (34.3)[a]	11/70 (15.7)[ba]	14/109 (12.8)[b]	0.018	37/214 (17.3)
Food insecure[4]	23/35 (65.7)[b]	59/70 (84.3)[ba]	95/109 (87.2)[a]	0.018	177/214 (82.7)
Mildly food insecure[4]	8/35 (22.9)	15/70 (21.4)	25/109 (22.9)	0.97	48/214 (22.4)
Moderately food insecure[4]	6/35 (17.1)	15/70 (21.4)	17/109 (15.6)	0.61	38/214 (17.8)
Severely food insecure[4]	9/35 (25.7)	29/70 (41.4)	53/109 (48.6)	0.06	91/214 (42.5)

[1]Values in a row with a differing letter statistically differ from each other at $\alpha \leq 0.05$ by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.
[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.
[3]Any oyster consumption was defined as oyster consumption > 0 g in the repeat 24-hour dietary recalls.
[4]Household food insecurity was assessed using the Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2007).

3.3. Percentages of women who consumed food from different food groups, mean food group dietary diversity score, and minimum dietary diversity for women

The summary results of the percentages of women who consumed food from different food groups, mean food group dietary diversity score, and minimum dietary diversity for women are presented in Table 8 for Ghana, and Table 9 for The Gambia. Across the three sites in Ghana, the mean 10-food group dietary diversity score was low (3.6 – 3.8), and only 20-23 percent of women achieved the minimum dietary diversity for women or had a food group dietary diversity score ≥ 5. These indices did not differ significantly by estuary site. In Ghana, 97-99 percent of women shellfishers across the three estuary sites consumed grains/white roots/tubers and plantains, and > 86 percent reportedly consumed meat, poultry, and fish during the 24 hours preceding enrollment into the study. The three sites did not differ in the percentage of women who consumed meat, poultry, and fish (P = 0.93); eggs (P = 0.12); and dark green leafy vegetables (P = 0.41). Large percentages of women consumed other vegetables besides dark green leafy vegetables. These percentages were lower for the Whin site (85 percent) than the Densu (97 percent) and Narkwa (94 percent) sites, P = 0.001).

In The Gambia, the mean 10-food group dietary diversity score was between 4.9 and 5.1 across sites, and 56-71 percent of women achieved the minimum dietary diversity for women or had a food group dietary diversity score ≥ 5. These indices did not differ significantly across the sites. Nearly all of the women shellfishers across the three estuary sites consumed grains/white roots/tubers and plantains, or meat, poultry, and fish during the 24 hours preceding enrollment into the study. The three sites did not differ in the percentage of women who consumed meat, poultry, and fish (P = 0.44); eggs (P = 0.76); and dark green leafy vegetables (P = 0.25). Relatively large percentages of women consumed other vegetables besides dark green. These percentages were higher for the Bulock site (80 percent) than the Allahein (49 percent) and the Tanbi (51 percent) sites (P < 0.001).

Table 8: Percentages of women who consumed food from different food groups, mean food group dietary diversity score, and minimum dietary diversity for women shellfishers 15-49 years of age who participated in the study, by estuary site, in Ghana[1].

	Estuary sites in Ghana				
	Densu	Narkwa	Whin	P[2]	Total
Grains/white roots/tubers and plantains	193/200 (96.5)	163/166 (98.2)	136/137 (99.3)	0.26	492/503 (97.8)
Pulses	22/200 (11.0)	18/166 (10.8)	14/137 (10.2)	0.97	54/503 (10.7)
Nuts and seeds	40/200 (20.0)[ba]	41/166 (24.7)[a]	16/137 (11.7)[b]	0.018	97/503 (19.3)
Milk and milk products	25/200 (12.5)[a]	4/166 (2.4)[b]	15/137 (10.9)[a]	0.006	44/503 (8.7)
Meat, poultry and fish	175/200 (87.5)	145/166 (87.3)	118/137 (86.1)	0.93	438/503 (87.1)
Eggs	33/200 (16.5)	16/166 (9.6)	23/137 (16.8)	0.12	72/503 (14.3)
Dark green, leafy vegetables	26/200 (13.0)	22/166 (13.3)	12/137 (8.8)	0.41	60/503 (11.9)
Vitamin A-rich fruits and vegetables	23/200 (11.5)[b]	55/166 (33.1)[a]	32/137 (23.4)[a]	<0.001	110/503 (21.9)
Other vegetables	194/200 (97.0)[a]	156/166 (94.0)[a]	117/137 (85.4)[b]	0.001	467/503 (92.8)
Other fruits	11/200 (5.5)	15/166 (9.0)	5/137 (3.6)	0.15	31/503 (6.2)
MDD-W 10-food group diversity score[3]	3.7 ± 1.0 (200)	3.8 ± 1.0 (166)	3.6 ± 1.3 (137)	0.12	3.7 ± 1.1 [503]
Achieved MDD-W (DDS ≥ 5)	40/200 (20.0)	39/166 (23.5)	27/137 (19.7)	0.65	106/503 (21.1)

[1]Values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.

[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.

[3]10-food group dietary diversity score (DDS) was calculated based on procedures described by the Food and Agricultural Organization (FAO, 2021); MDD-W: minimum dietary diversity for women.

Table 9: Percentages of women who consumed food from different food groups, mean food group dietary diversity score, and minimum dietary diversity for women shellfishers 15-49 years of age who participated in the study, by estuary site, in The Gambia[1].

	Estuary sites in The Gambia				
	Allahein	Bulock	Tanbi	P[2]	Total
Grains/white roots/tubers and plantains	35/35 (100)	69/70 (98.6)	108/109 (99.1)	0.95	212/214 (99.1)
Pulses	15/35 (42.9)[a]	14/70 (20.0)[b]	16/109 (14.7)[b]	0.003	45/214 (21.0)
Nuts and seeds	10/35 (28.6)	26/70 (37.1)	42/109 (38.5)	0.56	78/214 (36.4)
Milk and milk products	23/35 (65.7)[a]	27/70 (38.6)[b]	51/109 (46.8)[ba]	0.036	101/214 (47.2)
Meat, poultry and fish	35/35 (100)	69/70 (98.6)	103/109 (94.5)	0.44	207/214 (96.7)
Eggs	6/35 (17.1)	12/70 (17.1)	23/109 (21.1)	0.76	41/214 (19.2)
Dark green, leafy vegetables	11/35 (31.4)	30/70 (42.9)	34/109 (31.2)	0.25	75/214 (35.0)
Vitamin A-rich fruits and vegetables	17/35 (48.6)[b]	56/70 (80.0)[a]	56/109 (51.4)[b]	<0.001	129/214 (60.3)
Other vegetables	25/35 (71.4)	50/70 (71.4)	81/109 (74.3)	0.89	156/214 (72.9)
Other fruits	2/35 (5.7)[a]	2/70 (2.9)[a]	16/109 (14.7)[a]	0.040	20/214 (9.3)
MDD-W 10-food group diversity score[3]	5.1 ± 1.3 (35)	5.1 ± 1.6 (70)	4.9 ± 1.6 (109)	0.56	5.0 ± 1.5 [214]
Achieved MDD-W (DDS ≥ 5)	25/35 (71.4)	44/70 (62.9)	61/109 (56.0)	0.25	130/214 (60.7)

[1]Values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.

[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.

[3]10-food group dietary diversity score (DDS) was calculated based on procedures described by the Food and Agricultural Organization (FAO, 2021); MDD-W: minimum dietary diversity for women.

3.4. Hb concentration and anemia status

The mean blood hemoglobin concentrations and anemia status of the women shellfishers by estuary site in Ghana and The Gambia are presented in **Table 10** and **Table 11**, respectively. In Ghana, mean ± SD blood hemoglobin concentration (g/dl) was significantly higher (P <0.001) in women shellfishers at the Whin site (13.4 ± 1.5) than those at the Densu (12.7 ± 1.7) and Narkwa (12.9 ± 1.4) sites. The percent of women with anemia (Hb < 12 g/dl) ranged from 15 percent at the Whin site to 25 percent at the Densu site–with the Narkwa site in between at 19 percent–and did not differ across sites (P = 0.08). Similar trends were found for mild anemia (Whin, 14 percent; Narkwa, 16 percent; Densu, 19 percent: P = 0.51), moderate anemia (Whin, 1 percent; Narkwa, 2 percent; Densu, 5 percent: P = 0.17), and severe anemia (Whin, 0 percent; Narkwa, 1 percent; Densu, 2 percent: P = 0.73).

In The Gambia, mean ± SD blood hemoglobin concentration (g/dl) at the Allahein (12.2 ± 1.3), Bulock (12.1 ± 1.1), and Tanbi (12.4 ± 1.2) sites did not differ (P = 0.24). The percent of women with anemia (Hb < 12 g/dl) ranged from 38 percent at the Tanbi site to 46 percent at the Bulock site, with the Allahein site in between at 43%. These percentages did not differ across sites (P = 0.55). Similar trends were found for mild anemia (Tanbi, 37 percent; Allahein, 37 percent; Bulock, 41 percent: P = 0.81) and moderate anemia (Tanbi, 1 percent; Allahein, 6 percent; Bulock, 4 percent: P = 0.29). No women had severe anemia in The Gambia.

Table 10: Mean blood hemoglobin concentration and anemia status of women shellfishers 15-49 years of age who participated in the study, by estuary site, in Ghana[1].

	Estuary sites in Ghana				
	Densu	Narkwa	Whin	P[2]	Total
Hemoglobin concentration, g/dl	12.7 ± 1.7 (200)[b]	12.9 ± 1.4 (166)[b]	13.4 ± 1.5 (138)[a]	<0.001	12.9 ± 1.6 [504]
Any anemia, Hb < 12 g/dl	50/200 (25.0)	32/166 (19.3)	21/138 (15.2)	0.08	103/504 (20.4)
Mild anemia, Hb 10.0-11.9 g/dl	37/200 (18.5)	27/166 (16.3)	19/138 (13.8)	0.51	83/504 (16.5)
Moderate anemia, Hb 7.0-9.9 g/dl	10/200 (5.0)	4/166 (2.4)	2/138 (1.4)	0.17	16/504 (3.2)
Severe anemia, Hb b < 7 g/dl	3/200 (1.5)	1/166 (0.6)	0	0.73	4/504 (0.8)

[1]Values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.
[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.

Table 11: Mean blood hemoglobin concentration and anemia status of women shellfishers 15-49 years of age who participated in the study, by estuary site, in The Gambia[1].

	Estuary sites in The Gambia				
	Allahein	Bulock	Tanbi	P[2]	Total
Hemoglobin concentration, g/dl	12.2 ± 1.3 (35)	12.1 ± 1.1 (70)	12.4 ± 1.2 (109)	0.24	12.2 ± 1.2 [214]
Any anemia, Hb < 12 g/dl	15/35 (42.9)	32/70 (45.7)	41/109 (37.6)	0.55	88/214 (41.1)
Mild anemia, Hb 10.0-11.9 g/dl	13/35 (37.1)	29/70 (41.4)	40/109 (36.7)	0.81	82/214 (38.3)
Moderate anemia, Hb 7.0-9.9 g/dl	2/35 (5.7)	3/70 (4.3)	1/109 (0.9)	0.29	6/214 (2.8)
Severe anemia, Hb b < 7 g/dl	0	0	0	.	0

[1]Values in a row with a differing letter statistically differ from each other at α ≤ 0.05 by ANOVA and Tukey-Kramer tests for means and by Chi squared test for percentages.
[2]P-value compares within country the three group means by ANOVA or percentages by Chi squared test.

3.5. Association of household wealth-poverty level and any oyster consumption with household food insecurity

The adjusted percentages (95 percent CIs) and relative risk (95 percent CIs) of household food insecurity from the multivariate Poisson regression assessing associations of household wealth-poverty level and any oyster consumption in the repeat 24-hr recalls with household food insecurity among the women shellfishers in Ghana–controlling for estuary site and additional covariates associated with household food insecurity at an alpha of 0.2–are presented in **Table 12**. Those for the women shellfishers in The Gambia are presented in **Table 13**.

Table 12: Adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of household food insecurity according to selected background factors among women shellfishers 15-49 years of age who participated in the study in Ghana[1].

Background factors[2]	n (%)	Percent (95% CI) with HH food insecurity[3]	Relative Risk (95% CI) of HH food insecurity[4]	P
Wealth-poverty score ≥ site median value = 4				
No	227 (45.3)	86 (79, 93)	0.9 (0.8, 1.0)	0.021
Yes	274 (54.7)	96 (93, 100)		.
Any oyster consumption (> 0 g)				
No	441(87.5)	92 (89, 95)	1.0 (0.9, 1.1)	0.76
Yes	63 (12.5)	91 (84, 98)		.
Estuary site				
Narkwa	166 (32.9)	93 (88, 99)	1.0 (0.9, 1.1)	0.98
Whin	138 (27.4)	88 (82, 95)	0.9 (0.9, 1.0)	0.17
Densu	200 (39.7)	93 (90, 97)		.

[1]Total n = 504. HH = Household.

[2]Additinal covariates were selected if they were significantly associated with household food insecurity at an alpha of 0.2 in a Pearson correlation analysis. These additional covariates (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) married, (iii) done any job for cash or in-kind payment in the past 7 days, (iv) purchased any chicken eggs in the past month, (v) house outer wall made of cement, (vi) main fuel for cooking is LPG, (vii) any household member owns a fridge, (viii) any household member owns a fan, (ix) any household member owns a television, (x) any household member owns a mobile phone, (xi) any household member owns a canoe, (xii) consumed milk and milk products, (xiii) chicken eggs, (xiv) vitamin A-rich fruits and vegetables, and (xv) other vegetables in the 24 hours before enrollment.

[2]Percentage of women with household food insecurity and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param* = *glm*).

[2]Relative Risks and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param* = *ref*).

In Ghana, 15 other covariates (coded 1 = yes; 0 = no) were selected through correlation analysis for inclusion in the final Poisson regression model, namely: (i) able to read properly, (ii) married, (iii) done any job for cash or in-kind payment in the past 7 days, (iv) purchased any chicken eggs in the past month, (v) house outer wall made of cement, (vi) main fuel for cooking is LPG, (vii) any household member owns a fridge, (viii) any household member owns a fan, (ix) any household member owns a television, (x) any household member owns a mobile phone, (xi) any household member owns a canoe, (xii) consumed milk and milk products, (xiii) chicken eggs, (xiv) vitamin A-rich fruits and vegetables, and (xv) other vegetables in the 24 hours before enrollment. WPS level (high/low) related significantly (P = 0.021) in opposite direction to household food insecurity, with 96 percent (95 percent CI: 93, 100) of women from richer households experiencing household food insecurity compared with 86 percent (95 percent CI: 79, 93) of women from poorer households. Any oyster consumption was not associated with household food insecurity in the multivariate analysis.

In The Gambia, 6 additional covariates were selected through correlation analysis for inclusion in the final Poisson regression model. These (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) purchased any raw or corned beef in the past month, (iii) house outer wall made of cement, (iv) any household member owns a gas stove, (v) consumed pulses, and (vi) milk and milk products in the 24 hours before enrollment. WPS level (high/low) related in opposite direction to household food insecurity, with 85 percent (95 percent CI: 78, 93) of women from richer households experiencing household food insecurity compared with 74 percent (95 percent CI: 62, 87) of women from poorer households. However, unlike Ghana, the p-value (0.12) was not significant. Any oyster consumption was not significantly associated with household food insecurity in the multivariate analysis (P = 0.89).

Table 13: Adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of household food insecurity according to selected background factors among women shellfishers 15-49 years of age who participated in the study in The Gambia[1].

Background factors[2]	n	Percent (95% CI) with HH food insecurity[3]	Relative Risk (95% CI) of HH food insecurity[4]	P
Wealth poverty score ≥ site median value = 5				
No	81 (37.8)	74 (62, 87)	0.9 (0.7, 1.0)	0.12
Yes	133 (62.2)	85 (78, 93)		
Any oyster consumption (> 0 g)				
No	199 (93.0)	81 (74, 89)	1.0 (0.7, 1.4)	0.89
Yes	15 (7.0)	79 (58, 108)		.
Estuary site				
Bulock	70 (32.7)	74 (64, 87)	1.1 (0.8, 1.6)	0.59
Tanbi	109 (50.9)	91 (82, 100)	1.4 (0.9, 1.9)	0.10
Allahein	35 (16.4)	67 (48, 94)		.

[1] Total n = 214. HH = Household.

[2]Additional covariates were selected if they were significantly associated with household food insecurity at an alpha of 0.2 in a Pearson correlation analysis. These additional covariates (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) purchased any raw or corned beef in the past month, (iii) house outer wall made of cement, (iv) any household member owns a gas stove, (v) consumed pulses, and (vi) milk and milk products in the 24 hours before enrollment.

[3]Percentage of women with household food insecurity and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param* = *glm*).

[4]Relative Risks and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param* = *ref*).

3.6. Association of household wealth-poverty level and any oyster consumption with minimum dietary diversity for women (MDD-W)

The adjusted percentages (95 percent CIs) and relative risk (95 percent CIs) of achieving MDD-W from the multivariate Poisson regression assessing associations of household wealth-poverty level and any oyster consumption in the repeat 24-hr recalls with the achievement of MDD-W among the women shellfishers in Ghana–controlling for estuary site and other covariates associated with the achievement of MDD-W at an alpha of 0.2–are presented in **Table 14**. Those for the women shellfishers in The Gambia are presented in **Table 15**.

Table 14: Adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of achieving MDD-W according to selected background factors among women shellfishers 15-49 years of age who participated in the study in Ghana[1].

Background factors[2]	n (%)	Percent (95% CI) achieving MDD-W[3]	Relative Risk (95% CI) of achieving MDD-W[4]	P
Wealth poverty score ≥ site median value = 4				
No	227 (45.3)	8 (5, 12)	1.0 (0.6, 1.7)	0.85
Yes	274 (54.7)	8 (5, 11)		.
Any oyster consumption (> 0 g)				
No	441(87.5)	8 (6, 11)	0.8 (0.6, 1.3)	0.42
Yes	63 (12.5)	9 (6, 14)		.
Estuary site				
Narkwa	166 (32.9)	10 (7, 16)	1.3 (0.8, 2.1)	0.31
Whin	138 (27.4)	6 (4, 10)	0.8 (0.5, 1.3)	0.39
Densu	200 (39.7)	8 (5, 12)		.

[1]Total n = 504. MDD-W, Minimum Dietary Diversity Score for women.
[2]Additinal covariates were selected if they were significantly associated with household food insecurity at an alpha of 0.2 in a Pearson correlation analysis. These additional covariates (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) did any job for cash or in-kind payment in the past 7 days, (iii) purchased any chicken eggs in the past month, (iv) purchased any raw or corned beef in the past month in the past month, (v) main fuel for cooking is LPG, (vi) any household member owns a television, (vii) consumed pulses, (viii) consumed nuts and seeds, (ix) consumed milk and milk products, (x) consumed meat, poultry and fish, (xi) consumed egg, (xii) consumed dark green leafy vegetables, and (xiii) consumed other vitamin A-rich fruits and vegetables in the 24 hours before enrollment.
[2]Percentage of women with household food insecurity and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param = glm*).
[2]Relative Risks and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param = ref*).

In Ghana, 13 additional covariates were selected through correlation analysis for inclusion in the final Poisson regression model. These (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) did any job for cash or in-kind payment in the past 7 days, (iii) purchased any chicken eggs in the past month, (iv) purchased any raw or corned beef in the past month in the past month, (v) main fuel for cooking is LPG, (vi) any household member owns a television, (vii) consumed pulses, (viii) consumed nuts and seeds, (ix) consumed milk and milk products, (x) consumed meat, poultry and fish, (xi) consumed egg, (xii) consumed dark green leafy vegetables, and (xiii) consumed other vitamin A-rich fruits and vegetables in the 24 hours before enrollment. WPS level (high/low) and any oyster consumption were not associated with household food insecurity in the multivariate analysis.

In The Gambia, nine additional covariates were selected for the final Poisson regression model. The following variables were coded 1 = yes; 0 = no: (i) ever attended school, (ii) purchased any eggs in the past month, (iii) main fuel for cooking is wood, (iv) consumed pulses, (v) consumed nuts and seeds, (vi) consumed milk and milk products, (vii) consumed egg, (viii) consumed dark green leafy vegetables, and (ix) consumed other vitamin A-rich fruits and vegetables in the 24 hours before enrollment. WPS level (high/low) related significantly (P = 0.001) in opposite direction to the achievement of MDD-W, with 43 percent (95 percent CI: 37, 51) of women from richer households achieving MDD-W compared with 62 percent (95 percent CI: 53, 73) of women from poorer households. Any oyster consumption was not significantly associated with the achievement of the MDD-W in the multivariate analysis (P = 0.22).

Table 15: Adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of achieving MDD-W according to selected background factors among women shellfishers 15-49 years of age who participated in the study in The Gambia[1].

Background factors[2]	n (%)	Percent (95% CI) achieving of MDD-W[3]	Relative Risk (95% CI) of achieving MDD-W[4]	P
Wealth poverty score ≥ site median value = 5				
No	81 (37.8)	62 (53, 73)	1.4 (1.2, 1.8)	0.001
Yes	133 (62.2)	43 (37, 51)		
Any oyster consumption (> 0 g)				
No	199 (93.0)	49 (43, 56)	0.8 (0.6, 1.1)	0.22
Yes	15 (7.0)	60 (43, 82)		.
Estuary site				
Bulock	70 (32.7)	44 (36, 53)	0.7 (0.5, 0.9)	0.004
Tanbi	109 (50.9)	49 (42, 57)	0.8 (0.6, 1.0)	0.024
Allahein	35 (16.4)	65 (53, 80)		.

[1] Total n = 214. HH = Household.

[2]Additional covariates were selected if they were significantly associated with household food insecurity at an alpha of 0.2 in a Pearson correlation analysis. These additional covariates (coded 1 = yes; 0 = no) were: (i) ever attended school, (ii) purchased any eggs in the past month, (iii) main fuel for cooking is wood, (iv) consumed pulses, (v) consumed nuts and seeds, (vi) consumed milk and milk products, (vii) consumed egg, (viii) consumed dark green leafy vegetables, and (ix) consumed other vitamin A-rich fruits and vegetables in the 24 hours before enrollment.

[3]Percentage of women with household food insecurity and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param = glm*).

[4]Relative Risks and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param = ref*).

3.7. Association of household wealth-poverty level and any oyster consumption with anemia

The adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of anemia from the multivariate Poisson regression assessing associations household wealth-poverty level and any oyster consumption in the repeat 24-hr recalls with anemia status among the women shellfishers in Ghana–controlling for estuary site and other covariates associated with anemia status at an alpha of 0.2–are presented in **Table 16**. Those for the women shellfishers in The Gambia are presented in **Table 17**.

Table 16: Adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of any anemia according to selected background factors among women shellfishers 15-49 years of age who participated in the study in Ghana[1].

Background factors[2]	n (%)	Percent (95% CI) with any anemia[3]	Relative Risk (95% CI) of any anemia[4]	P
Wealth poverty score ≥ site median value = 4				
No	227 (45.3)	18 (13, 24)	1.0 (0.7, 1.6)	0.90
Yes	274 (54.7)	18 (13, 23)		.
Any oyster consumption (> 0 g)				
No	441(87.5)	17 (14, 21)	0.7 (0.4, 1.1)	0.08
Yes	63 (12.5)	26 (17, 40)		.
Estuary site				
Narkwa	166 (32.9)	17 (12, 24)	0.8 (0.5, 1.2)	0.28
Whin	138 (27.4)	15 (10, 21)	0.7 (0.4, 1.0)	0.09
Densu	200 (39.7)	22 (17, 29)		.

[1]Total n = 504.
[2]Additinal covariates were selected if they were significantly associated with household food insecurity at an alpha of 0.2 in a Pearson correlation analysis. These additional covariates (coded 1 = yes; 0 = no) were: (i) ever attend school, (ii) being married, (iii) main fuel for cooking is LPG, (iv) any household member owns a gas stove, (v) being overweight or obese, and (vi) consumed dark green leafy vegetables in the 24 hours before enrollment.
[3]Anemic percentages and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param = glm*).
[4]Relative Risks and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param = ref*).

In Ghana, six additional covariates were selected through correlation analysis for inclusion in the final Poisson regression model. These covariates (coded 1 = yes; 0 = no) were: (i) ever attend school, (ii) being married, (iii) main fuel for cooking is LPG, (iv) any household member owns a gas stove, (v) being overweight or obese, and (vi) consumed dark green leafy vegetables in the 24 hours before enrollment. Neither wealth-poverty level (high/low) nor any oyster consumption in the repeat 24-hr recalls was associated with anemia prevalence in the multivariate analysis.

Table 17: Adjusted percentages (95 percent CIs) and relative risks (95 percent CIs) of any anemia according to selected background factors among women shellfishers 15-49 years of age who participated in the study in The Gambia[1].

Background factors[2]	n	Percent (95% CI) with any anemia[3]	Relative Risk (95% CI) of any anemia[4]	P
Wealth poverty score ≥ site median value = 5				
No	81 (37.8)	34 (21, 55)	0.9 (0.5, 1.7)	0.86
Yes	133 (62.2)	36 (26, 48)		
Any oyster consumption (> 0 g)				
No	199 (93.0)	37 (29, 46)	2.1 (0.6, 7.1)	0.23
Yes	15 (7.0)	17 (5, 58)		.
Estuary site				
Bulock	70 (32.7)	43 (30, 62)	1.7 (0.9, 3.3)	0.12
Tanbi	109 (50.9)	33 (23, 48)	1.3 (0.6, 2.8)	0.48
Allahein	35 (16.4)	25 (13, 48)		.

[1] Total n = 214.
[2]Additinal covariates were selected if they were significantly associated with household food insecurity at an alpha of 0.2 in a Pearson correlation analysis. These additional covariates (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) being married, (iii) did any job for cash or in-kind payment in the 7 days before enrollment, (iv) any household member owns a television, (v) any household member owns a canoe, and (vi) consumed dark green leafy vegetables in the 24 hours before enrollment.
[3]Anemic percentages and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param* = *glm*).
[4]Relative Risks and 95% CIs were generated using by Poisson regression (SAS PROC GENMOD, option *param* = *ref*).

In The Gambia, six additional covariates were selected through correlation analysis for the final Poisson regression model. These (coded 1 = yes; 0 = no) were: (i) able to read properly, (ii) being married, (iii) did any job for cash or in-kind payment in the seven days before enrollment, (iv) any household member owns a television, (v) any household member owns a canoe, and (vi) consumed dark green leafy vegetables in the 24 hours before enrollment. As in Ghana, neither wealth-poverty level (high/low) nor any oyster consumption in the repeat 24-hr recalls was associated with anemia prevalence in the multivariate analysis.

3.6. Mineral and heavy metal concentrations of oysters collected from three estuarine sites in Ghana

The mineral and heavy metal concentrations (mg/kg wet weight) of the oyster samples collected from the Densu, Narkwa, and Whin estuarine sites are summarized in **Table 18**.

The oysters from the three estuarine sites in Ghana differed significantly in the mean concentrations (mg/kg wet weight) of all the minerals and heavy metals measured. There was no consistent pattern of higher or lower mean macromineral (Ca, Mg, P, K, and Na) concentrations of the oyster samples by estuarine site. However, the mean trace mineral (Cr, Co, Cu, Fe, Mn, Ni, Se, and Zn) and heavy metal (As, Cd, Pb, and Hg) concentrations were consistently higher in the Narkwa samples than these from the Densu and Whin sites. For example, the mean ± SD Fe concentration of the oysters from the

Narkwa site was 147 ± 142, compared with 125 ± 91 for the Densu site and 103 ± 87) for the Whin site ($P < 0.001$). Likewise, the mean Zn concentration was higher in the oysters from Narkwa (118 ± 79) than those from Densu (64.0 ± 56.4) and Whin (65.5 ± 62.1) ($P < 0.001$). The mean ± SD heavy metal concentrations of oysters from across the three sites ranged from 0.043 ± 0.032 – 0.189 ± 0.167 for total As, 0.011 ± 0.008 – 0.047 ± 0.042 for i-As (estimated at an average of 25 percent of total arsenic), 0.023 ± 0.017– 0.065 ± 0.051 for Cd, 0.016 ± 0.022 – 0.057 ± 0.046 for Pb, and 0.022 ± 0.025 – 0.065 ± 0.132 for Hg, with oysters from the Narkwa site having significantly higher ($P \leq 0.002$) mean concentration for all four heavy metals compared with the other two sites.

Table 18: Macrominerals, trace minerals, and heavy metal concentrations of oysters collected from three estuary sites in Ghana.

Mineral, mg/kg wet weight	Densu (n = 305)	Narkwa (n = 305)	Whin (n = 305)	P	All (n = 915)
Macrominerals					
Calcium	3811 ± 2878[a]	837 ± 942[b]	3445 ± 4081[a]	<0.001	2698 ± 3216
Magnesium, mg/kg	1321 ± 453[a]	1116 ± 409[b]	374 ± 264[c]	<0.001	937 ± 559
Phosphorus, mg/kg	2882 ± 2219[b]	5016 ± 8367[a]	2513 ± 3101[b]	<0.001	3470 ± 5416
Potassium, mg/kg	8314 ± 5620[a]	3090 ± 2181[b]	1443 ± 755[c]	<0.001	4282 ± 4567
Sodium, mg/kg	8051 ± 5315[b]	9689 ± 2990[a]	3031 ± 2929[c]	<0.001	6924 ± 4822
Trace minerals					
Chromium, mg/kg	0.331 ± 0.246[b]	0.737 ± 0.512[a]	0.294 ± 0.269[b]	<0.001	0.453 ± 0.413
Cobalt, mg/kg	0.043 ± 0.043[c]	0.086 ± 0.078[a]	0.065 ± 0.166[b]	<0.001	0.064 ± 0.110
Copper, mg/kg	1.5 ± 1.2[b]	3.2 ± 2.1[a]	1.4 ± 1.3[b]	<0.001	2.0 ± 1.8
Iron, mg/kg	126 ± 90[b]	147 ± 142[a]	103 ± 87[c]	<0.001	126 ± 111
Manganese, mg/kg	1.2 ± 1.1[b]	2.8 ± 2.1[a]	1.1 ± 1.3[b]	<0.001	1.7 ± 1.7
Nickel, mg/kg	0.539 ± 0.446[b]	1.16 ± 1.07[a]	0.631 ± 0.807[b]	<0.001	0.776 ± 0.858
Selenium	4.6 ± 3.6[b]	5.9 ± 7.4[a]	5.7 ± 6.2[a]	0.014	5.4 ± 6.0
Zinc, mg/kg	64.0 ± 56.3[b]	118 ± 79[a]	65.5 ± 62.1[b]	<0.001	82 ± 71
Heavy metals					
Arsenic (total)	0.043 ± 0.032[c]	0.189 ± 0.167[a]	0.079 ± 0.116[b]	<0.001	0.102 ± 0.132
Arsenic (inorganic)	0.011 ± 0.008[c]	0.047 ± 0.042[a]	0.020 ± 0.029[b]	<0.001	0.025 ± 0.033
Cadmium	0.023 ± 0.017[b]	0.065 ± 0.051[a]	0.025 ± 0.027[b]	<0.001	0.037 ± 0.039
Lead	0.021 ± 0.021[b]	0.057 ± 0.046[a]	0.016 ± 0.022[b]	0.002	0.032 ± 0.037
Mercury	0.027 ± 0.038[b]	0.065 ± 0.132[a]	0.022 ± 0.025[b]	<0.001	0.038 ± 0.083

Table 19 shows that none of the oysters collected from the three sites exceeded the maximum concentration limits for As, Cd or Pb, according to international guidelines. Only one oyster sample from the Narkwa site exceeded the maximum concentration limit for Hg. The mean EDIs (mg/kg body weight/day) of the four heavy metals in oysters among the women shellfishers ranged from 1.2×10^{-6} to 5.4×10^{-6} for i-As, 2.5×10^{-6} to 7.3×10^{-6} for Cd, 1.2×10^{-6} to 6.5×10^{-6} for Pb, and 2.5×10^{-6} to 7.3×10^{-6} for Hg. Across the three estuarine sites, Narkwa had the highest mean EDI for all four heavy metals. The mean THQ for oyster consumption among women shellfishers across the three estuarine sites ranged from 4.1×10^{-3} to 1.8×10^{-2} for i-As, 2.5×10^{-3} to 7.3×10^{-3} for Cd, 9.0×10^{-3} to 3.3×10^{-2} for Pb, and 2.5×10^{-2} to 7.3×10^{-2} for Hg. The Narkwa site had the highest mean THQ for all four heavy metals when comparing with the two sites. All three sites had a mean THQ value that was well

below 1 for each of the four heavy metals, indicating that the average level of each heavy metal in oysters at each of the three sites was lower than the oral reference dose.

Across the three sites, mean HI for oyster consumption among the women shellfishers ranged from 0.04 at the Whin site to 0.13 at the Narkwa site; none of the estuarine site had a mean HI exceeding 1. At all three sites, the primary driver of the HI values among the women shellfishers was Hg accounting for 50-57 percent, followed by Pb accounting for 22 -29 percent, and with Cd contributing the least (6-8 percent).

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Table 19: Estimated Daily Intake (EDI), Target Hazard Quotient (THQ) and Hazard Index (HI) for oyster consumption among women shellfishers at three estuarine sites in Ghana.[1.]

Heavy metal	% of oysters with metal concentration above maximum regulatory limit[2]	Mean (Min, Max) EDI (mg/kg BW /day)[3]	Mean (Min, Max) THQ[4]	Mean (Min, Max) HI[5]	Mean % contribution to HI
Arsenic (inorganic)[6]					
All	0	2.9×10^{-6} (3.4×10^{-8}, $3.4\ 10^{-5}$)	9.6×10^{-3} (1.0×10^{-4}, 1.1×10^{-1})		15.3
Densu	0	1.2×10^{-6} (2.6×10^{-7}, 7.3×10^{-6})	4.1×10^{-3} (9.0×10^{-4}, 2.4×10^{-2})		10.5
Narkwa	0	5.4×10^{-6} (3.4×10^{-8}, 3.2×10^{-5})	1.8×10^{-2} (1.0×10^{-4}, 1.1×10^{-2})		17.0
Whin	0	2.2×10^{-6} (3.4×10^{-8}, 3.4×10^{-5})	7.5×10^{-3} (1.0×10^{-4}, 1.1×10^{-2})		18.6
Cadmium					
All	0	4.2×10^{-6} (3.4×10^{-7}, 3.8×10^{-5})	4.2×10^{-3} (3.0×10^{-4}, 3.8×10^{-2})		7.2
Densu	0	2.6×10^{-6} (5.7×10^{-7}, 1.7×10^{-5})	2.5×10^{-3} (6.0×10^{-4}, 1.7×10^{-2})		6.4
Narkwa	0	7.3×10^{-6} (3.4×10^{-7}, 3.8×10^{-5})	7.3×10^{-3} (3.0×10^{-4}, 3.8×10^{-2})		6.9
Whin	0	2.9×10^{-6} (3.4×10^{-7}, 2.4×10^{-5})	2.9×10^{-3} (3.0×10^{-4}, 2.4×10^{-2})		8.2
Lead					
All	0	3.6×10^{-6} (1.1×10^{-7}, 3.1×10^{-5})	1.8×10^{-2} (6.0×10^{-4}, 1.6×10^{-1})		26.1
Densu	0	2.4×10^{-6} (1.1×10^{-7}, 1.7×10^{-5})	1.2×10^{-2} (6.0×10^{-4}, 8.3×10^{-2})		27.3
Narkwa	0	6.5×10^{-6} (1.1×10^{-7}, 3.1×10^{-5})	3.3×10^{-2} ($6.0 \times 10\text{-}^{-4}$, 1.6×10^{-1})		29.0
Whin	0	1.8×10^{-6} (1.1×10^{-7}, 1.8×10^{-5})	9.0×10^{-3} (6.0×10^{-4}, 8.9×10^{-2})		21.7
Mercury					
All	1	4.3×10^{-6} (0, 1.5×10^{-4})	4.3×10^{-2} (0, 1.5)		54.1

Heavy metal	% of oysters with metal concentration above maximum regulatory limit[2]	Mean (Min, Max) EDI (mg/kg BW /day)[3]	Mean (Min, Max) THQ[4]	Mean (Min, Max) HI[5]	Mean % contribution to HI
Densu	0	3.1×10^{-6} $(0, 6.4 \times 10^{-5})$	3.1×10^{-2} $(0, 6.4 \times 10^{-1})$		57.3
Narkwa	1	7.3×10^{-6} $(4.5 \times 10^{-7}, 1.5 \times 10^{-4})$	7.3×10^{-2} $(4.5 \times 10^{-3}, 1.5)$		50.2
Whin	0	2.5×10^{-6} $(0, 2.2 \times 10^{-5})$	2.5×10^{-2} $(0, 2.2 \times 10^{-1})$		54.7
Cumulative potential health risk					
All				0.07 (0.01, 1.55)	
Densu				0.05 (0.01, 0.72)	
Narkwa				0.13 (0.01, 1.55)	
Whin				0.04 (0.01, 0.22)	

[1]Oyster samples were *n* = 305 for each of the Densu, Narkwa Whin sites (total n = 915).
[2]Maximum regulatory limit (mg/kg wet wt) were specified by the Food Standards Australia and New Zealand (FSANZ, 2020) for inorganic arsenic (1.0) and by the EU/FAO for Cd (1.0), Pb (1.5), and Hg (1.0) (EU/FAO, 2006).
[3]EDI: Estimated Daily Intake of metals expressed as mg/kg body weight/day was calculated by dividing the product of the oyster metal concentration (mg/kg wet weight) and average daily oyster consumption of women shellfishers (kg) by the average body weight of women shellfishers (kg) (Bristy et al., 2021; Yap et al., 2020)
[4]THQ, Target Hazard Quotient, is the ratio of exposure (Estimated Daily Intake, EDI) to the oral reference dose (RfD) (Joseph et al., 2021). The RfD (mg/kg BW/day) values for As (0.0003) and Cd (0.001) were reported by the USEPA (Moslen & Miebaka, 2017; USEPA, 2018) ; RfD values for lead (0.0002) (Lim et al., 2012) and mercury (0.0001) (Holloman & Newman, 2012) were not available from USEPA (USEPA, 2018).
[5]HI, Hazard Index, is the sum of the THQ of all the heavy metals (Joseph et al., 2021; Moslen & Miebaka, 2017), i.e., HI = $THQ_{arsenic}$ $THQ_{cadmium} + THQ_{lead} + THQ_{mercury}$. HI > 1 indicates potential health risk.
[6]Values refer to the average inorganic contents of arsenic in the oyster samples estimated conservatively at 25% of the total As concentration (Lorenzana et al., 2009).

4. DISCUSSION

This report presents food intake, food insecurity, dietary diversity, and anemia prevalence among women shellfishers living at oyster estuary sites in Ghana and The Gambia, as well as mineral and heavy metal concentrations of oysters in Ghana. We found that women shellfishers across the three estuarine sites in Ghana differed in mean oyster intakes, percentage of women who consumed any oyster in the repeat 24-hour dietary recalls, and percentage of women with mild or severe food insecurity. In The Gambia, women shellfishers across the three sites differed in the percentage with any food insecurity. There was no consistent pattern of higher or lower oyster intakes and food insecurity rate by estuary site in Ghana or The Gambia. In either country, women shellfishers across three estuarine sites did not differ in mean 10-food group dietary diversity score, the percentage of women who achieved the minimum dietary diversity for women (food group dietary diversity score ≥ 5), or prevalence of anemia. In multivariate analyses within country (controlling for estuarine site and additional background factors), WPS level (high/low) related significantly in opposite direction to household food insecurity in Ghana and the achievement of MDD-W in The Gambia. Apart from these, WPS level and any oyster consumption were not associated with household food insecurity, achievement of MDD-W, or anemia status. These results do not support our hypothesis that higher wealth-poverty level and oyster consumption were associated with lower household food insecurity, greater likelihood of achieving MDD-W, and lower prevalence of anemia among women shellfishers in Ghana and The Gambia. Finally, none of the oysters from the three sites exceeded the maximum concentration limit for As, Cd, Pb, and Hg based on international guidelines, except for one oyster sample from the Narkwa site, which exceeded the maximum concentration limit for Hg only. The mean cumulative Hazard Index for oyster consumption among the women shellfishers was below 1; none of the estuarine site had a mean HI exceeding 1. At all three sites, the primary driver of the HI values among the women shellfishers was Hg accounting followed by lead, with Cd contributing the least.

This study had several strengths, including a relatively large sample size comprising nearly all the women shellfishers in the target age group at each of the estuarine sites in Ghana and The Gambia. We used repeat 24-hr dietary recall to assess dietary intake, which is currently the gold standard and provides a better estimates of daily nutrient intakes than either a food frequency questionnaire, or a single 24-hr recall (Olafsdottir, Thorsdottir, Gunnarsdottir, Thorgeirsdottir, & Steingrimsdottir, 2006). To our knowledge, this is the first study in Ghana in which such a large number of oyster samples (>900) were analyzed for a total of 13 minerals and 4 heavy metals. One weakness of the study was our reliance on recall methods to assess dietary intake which could possibly have led to less accurate estimates of intakes because women had to remember what they consumed in the 24-hr before the interview. Another weakness is that there were no specific or reliable food composition tables for Ghana and The Gambia. Thus, for some food items consumed, we chose similar or identical foods from the West African Food Composition Table (FAO, June, 2012) or the United States Department of Agriculture (USDA, February, 2011) database. These similar or identical foods may have different nutrient contents than the foods consumed, and therefore, at least some of the nutrient intakes may be over- or under-estimated. However, those similar or identical foods were relatively few. Lastly, as we tested many hypotheses in this study, it is possible that some of the observed differences may be due to chance (Li et al., 2017).

Oyster consumption was low in both countries, with only 13 percent of women in Ghana and 7 percent of women in The Gambia reporting any oyster consumption. Given that we collected the dietary intake data in the months of June and July when the oyster-harvesting season was open and there was supposedly more access to oysters, it is likely that oyster intakes at different times of the year (e.g., during closed oyster season) may even be lower than our estimated amounts. However, one key informant from TRY reported women often dry and save oysters to consume during closed season periods.

Women in fishing communities in West Africa have often been reported to be food insecure due to factors such as depleting fish stocks (World Economic Forum, 2021), but the high prevalence of household food insecurity in our samples in Ghana and The Gambia seems extraordinary and may be partly the result of the COVID-19 pandemic at the time (June - July 2021) data were collected. In Ghana for example, about two-thirds of the population (~ 22 million people) reportedly experienced a decrease in household income, while 52 percent of households reduced food consumption due to the pandemic (UNICEF-World Bank, 2022). In The Gambia, food insecurity reportedly increased from 8 percent in 2016 to more than 13 percent in 2021, while the population at borderline food insecurity increased from 29 percent in 2016 to 60 percent in 2021 (WFP, 2021).

The prevalence of anemia in the Ghana sample (15 percent-25 percent) is consistent with the 22 percent reported for non-pregnant women 15-49 years by the Ghana Micronutrient Survey 2017 (UG/GroundWork/UWisconsin-Madison/KEMRI/UNICEF, 2017), while that in The Gambia (38 percent-46 percent) is consistent with the 44 percent reported by the country's Demographic and Health Survey 2019-20 (GBoS and ICF, 2019). In both countries, anemia rate has been consistently high among women of child-bearing age for decades (GBoS and ICF, 2019; GSS/GHS/ICF, 2015), primarily as a result of inadequate dietary iron intakes (Jamil et al., 2008; Stoltzfus, 2003).

There may be several possible explanations for the discrepancy between our hypothesis and the results in Ghana and The Gambia. It appears that across the estuarine sites in either country, oysters constitute a relatively small portion the overall dietary intakes of the women. This is seen in the small mean total daily oyster consumption among the women shellfishers in both countries (Tables 6 and 7). In a recent study examining the global (175 countries) consumption of aquatic animal source foods over the period from 1993 to 2013 (Iannotti et al., 2022), the median per capita daily intake of mollusks (including oyster) was 0.53 g. Thus, the low level of oyster consumption observed in this study (Ghana: 6.1 g, The Gambia: 1.9 g) may not be surprising. It is unlikely that such small oyster consumption would be directly associated with women's food security, achievement of MDD-W, and anemia prevalence. We do not know if the women use proceeds from oyster sales to acquire other food items, but we did not find that higher wealth-poverty level was associated with lower household food insecurity.

It is unclear why the women's oyster consumption in Ghana and The Gambia was low. The main reason might be that the women shellfishers sell a far greater proportion of harvested oysters for income than what they consume. In a study at Narkwa involving 45 females and 15 males randomly selected from different parts of the community (B. Asare, Obodai, & Acheampong, 2019), the majority of the sample (75 percent) reportedly harvested oysters for sale and consumption, but the proportion of harvested oysters actually consumed by women shellfishers may be small compared with the amount sold. In recent times, oyster harvesting has become an important livelihood activity in Ghana and The Gambia, so that women harvest oysters mainly for sale (Atindana, Fagbola, Ajani, Alhassan, & Ampofo-Yeboah, 2020). Another possible reason might be the belief that oysters may be contaminated with heavy metals and other pollutants from mining activities (Gbogbo, Otoo, Asomaning, & Huago, 2017), e-wastes (Affum, Oduro-Afriyie, Nartey, Adomako, & Nyarko, 2008; Teye & Tetteh, 2021), fecal matter (Osei, Chuku, Effah, Kent, & Crawford, 2021), and other solid wastes including garbage and plastics (Hayford, 2021). In this case, the women shellfishers are more likely to consume less and sell more of the oysters they harvest. It is likely that other aquatic animal source foods such as pelagic fishes contribute more to women's iron and zinc intakes (Iannotti et al., 2022) than oysters.

In an earlier report (E. O Chuku et al., 2022), the concentrations (mg/kg wet weight) of heavy metals (As, Cd, Pb, and Hg) in a pool of small oyster meat samples collected from the same estuarine sites in June 2021 were <0.02 for As, <0.01 for Cd, <0.10 for Pb, and <0.03 for Hg. Our observed heavy metal concentrations of oyster meat samples across the three sites are generally consistent with those from that earlier report (E. O Chuku et al., 2022). While the heavy metal concentrations of the oyster samples in our study were low, the relatively large mean values for the Narkwa oysters (compared with those from the other two sites) suggests a higher level of pollution in that area compared with the other two sites, as found previously (Otchere, 2019). Potential sources of the heavy metal contamination of the oysters at Narkwa site include artisanal small scale gold mining, which involves panning soil with elemental mercury (Gyamfi et al., 2021; World Bank Group, 2020); e-waste (Ackah, 2017; World Bank Group, 2020); and lead battery manufacturing and recycling (World Bank Group, 2020).

The low mean Hazard Index values for the three estuarine sites suggests that there is less likelihood of potentially substantial health hazard as a result of oyster consumption among the women shellfishers. The Se contents of the oyster meat may also provide benefits to women shellfishers at the three sites, given reports that Se counteracts the toxic effects of As, Cd, and Hg poisoning (Reilly, 2002). For example, selenium may offer protection from mercury and methylmercury toxicity by preventing cellular damage from free radicals through counteracting the mercury-induced depression in glutathione-synthesizing enzymes and the formation of inactive selenium-mercury complexes (Goyer, 1997). Thus, interactions between heavy metal ions may offer protection against heavy metal poisoning related to oyster consumption among women in the sample.

5. CONCLUSIONS AND RECOMMENDATIONS

1. Our results show that the current level of oyster consumption among the women shellfishers 15-49 years at the three estuarine sites in Ghana and their counterparts in The Gambia may be too low to make any substantial impact on the women's iron and zinc intakes from oyster, food security, dietary diversity, and anemia prevalence. The main possible explanation is that the women shellfishers sell a much larger proportion of the oysters they harvest than the proportion they consume. It is also likely that the women consume more of other aquatic animal source foods (e.g., small pelagic fishes) than they do oysters.
2. In Ghana, oysters from the three estuarine sites provide a rich source of dietary minerals, and heavy metal (As, Cd, Pb, and Hg) contamination related to oyster consumption does not appear to pose a health risk for women shellfishers.
3. We propose the following recommendations for further research:
   a. A focus group discussion among women shellfishers in Ghana and The Gambia to explore how women shellfishers might use their shellfishery resources more effectively to prevent anemia.
   b. Investigation into the reasons for the relatively high mean heavy metal concentrations of oysters from the Narkwa site in Ghana and their implications.
   c. Human health risk assessment of heavy metal concentration of oysters from the three estuarine sites in The Gambia, as done for those in Ghana.
4. We propose the following recommendations for programmatic action:
   a. Promote oyster consumption as a promising strategy to increase nutrient intakes and prevent anemia in estuarine communities in Ghana and The Gambia.
   b. Regular monitoring of Hg and Pb contamination of oysters and other aquatic animal foods in Ghana (especially at the Narkwa) and The Gambia.

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