WOMEN SHELLFISHERS AND FOOD SECURITY PROJECT

MULTIVARIATE ANALYSIS OF THE THEORY OF CHANGE MODEL

July 2022

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Citation: Crawford, B., Adu-Afarwuah, S., Oaks, B., Kyei-Arthur, F., Chuku, E. O., Okyere, I., Duguma, L., Carsan, S., McMullin, S., Muthee, K., Bah, A., Orero, L., Janha, F., Arnold, C. D., Kent, K. (2022). The Women Shellfishers and Food Security Project: Multivariate analysis of the theory of change model. Centre for Coastal Management, University of Cape Coast; World Agroforestry; Department of Nutrition and Food Science, University of Ghana; Department of Nutrition and Food Science and Coastal Resources Center, University of Rhode Island. Narragansett, RI, USA. WSFS2022_10_CRC. 105 pp.

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Prepared for USAID under the BAA-AFR-SD-2020 Addendum 01, (FAA No. 7200AA20FA00031) awarded on August 12, 2020 to the University of Rhode Island and entitled "Women Shellfishers and Food Security."

This document is made possible by the support of the American People through the United States Agency for International Development (USAID). The views expressed and opinions contained in this report are those of the Project team and are not intended as statements of policy of either USAID or the cooperating organizations. As such, the contents of this report are the sole responsibility of the authors and do not necessarily reflect the views of USAID or the United States Government.

Cover photo: Women harvesting oysters in the Whin Estuary (see mangrove vegetation fringing the estuary), Ghana.

Photo credit: Ernest Chuku, Africa Centre of Excellence in Coastal Resilience (Centre for Coastal Management), University of Cape Coast.

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ACRONYMS

CCM	Centre for Coastal Management
CRC	Coastal Resources Center
DO	Dissolved Oxygen
FFQ	Food Frequency Questionnaire
HFIAS	Household Food Insecurity Access Scale
ICRAF	World Agroforestry
IRB	Institutional Review Board
MDD-W	Minimum Dietary Diversity for Women
MAHFP	Months of Adequate Household Food Provisioning
RDA	Recommended Daily Allowance
TRY	TRY Oyster Women's Association
UCC	University of Cape Coast
UG	University of Ghana
URI	The University of Rhode Island
USAID	United States Agency for International Development
WEAI	Women's Empowerment in Agriculture Index
WSFS	Women Shellfishers and Food Security

EXECUTIVE SUMMARY

This report is a summary of a multivariate analysis of the theory of change model of the USAID Women Shellfishers and Food Security Project, funded by The United States Agency for International Development (USAID) and implemented by the University of Rhode Island (URI) and several partners from West Africa – the University of Cape Coast (UCC) in Ghana, the University of Ghana (UG), TRY Oyster Women's Association (TRY) in The Gambia and, World Agroforestry (ICRAF). This project seeks to address the need for greater attention to food security for women shellfishers and their families while improving biodiversity conservation of the mangrove and estuarine ecosystems on which their livelihoods depend.

The theory of change model put forth by this project was:

> *IF women's shellfish livelihoods in coastal mangrove and estuarine ecosystems in The Gambia and Ghana are improved through gender and nutrition sensitive co-management and linkages made to community based forest management in the land/seascape, THEN mangrove and estuarine biodiversity will be improved, AND IF approaches for sustainable food producing livelihoods within the coastal mangrove land/seascape contribute to a nutritionally balanced local food supply, THEN household resilience, sustainable food systems, and nutrition will improve.*

We refined this model and developed four major hypotheses statements to be assessed through site-based research. These were:

Hypothesis 1. Improved and gender equitable management of shellfisheries increases shellfish yields, which increases shellfish consumption and income of those engaged in shellfishing.

Hypothesis 2. Shellfisher mangrove management actions improve mangrove habitat which in turn improves the health of shellfish stocks.

Hypothesis 3. High consumption of shellfish and increased income from shellfishing contributes to lower prevalence of anemia in women of reproductive age and improves other nutrition variables. Shellfish consumption is a main contributor to reduced anemia compared to other factors such as geographic factors or household and individual characteristics.

Hypothesis 4. Enriching landscapes around mangrove-shellfish estuaries systems with complementary food and nutrition sources reduces the extractive pressure on the mangroves thereby improving mangrove health and improves shellfisher household income and household food security.

There is existing evidence that co-management of mangroves and fisheries are effective good practices as well as evidence that improved mangrove habitat can increase fisheries yields. In West Africa, women play an important role in estuarine fisheries management through substantial harvesting of

bivalves where women dominate all aspects of the value chain (Chuku et al., 2022a). There are two examples in West Africa where women shellfishers are successfully managing shellfisheries through a rights based, co-management approach which is also providing benefits for mangrove conservation (MOFAD, 2020; MFWR, 2012). This has good potential for scale up within the region. Less evidence exists on the impacts of improving proximate landscape food systems on food security and bio-diversity conservation, and nutritional benefits from shellfish consumption for women shellfishers. If demonstrated through this research, it would provide stronger empirical evidence for scaling up of and integrated approach of women-led shellfisheries management, mangrove management, and diversified food portfolios of shellfishing households in the proximate landscape.

Six sites in two West African countries were purposively selected for the study. These were the Densu, Narkwa, and Whin estuaries in Ghana, and the Tanbi, Allahein, and Bulock estuaries in The Gambia. Regional project partners collected field data including ICRAF, University of Ghana, TRY, and University of Cape Coast. We collected data on eight theme areas of the model:

1. Mangrove ecosystems
2. Shell fisheries
3. Estuarine water quality
4. Landscape level and household food systems
5. Governance of shellfisheries and mangroves
6. Empowerment of women shellfishers
7. Socio-economics of the shellfishery and of shellfishers:
8. Nutrition of women of reproductive age and household food security

Data was aggregated and used to empirically assess the hypothesized casual relationships in each of the four major hypotheses asserted above. We conducted statistical analysis for both case level analysis and site level analysis across the two countries and six sites combined.

The following is a summary the main findings from the analysis:

Hypothesis 1

- Sites with a higher governance score have a lower exploitation ratio and fishing mortality, and higher fishery health rank compared to sites with a lower governance score.
- Shellfish height - a shellfisheries health indicator - is greater in sites with a higher governance score.
- Fisheries health rank and mean shell height is higher and exploitation ratio and fishing mortality lower where women's empowerment scores are higher.
- Ghana sites have a higher mean temperature, pH, turbidity and a lower mean depth and salinity, as well as a shorter mean shell height than sites in The Gambia, but none of these differences were statistically significant.
- Underexploited sites have a greater mean shell height, a higher mean salinity and a greater mean depth compared to the fully and over-exploited sites but none of these differences were statistically significant.

- Underexploited sites have lower natural mortality rates as well as a higher mean salinity and a greater mean depth than fully and over-exploited sites.
- There were no statistically significant differences between the fishery health indicators and shellfish consumption or per capita food expenditures.
- Household income, shellfish livelihood dependency, and shellfish income are all higher in the underexploited sites. The poverty/wealth index shows higher poverty in the over and fully exploited sites. Livelihood diversity is lower in underexploited sites. However, only livelihood diversity and the poverty index showed statistical significance.
- There was no significant relationship between household income, livelihood dependence, shellfishing income or the poverty/wealth index and livelihood diversity.

Hypothesis 2

- There seems to be no relationship between shellfisher protections for mangroves and mangrove health for any of the measures used.
- There were no positive relationships between higher women's empowerment scores and higher mangrove health on any of any of the mangrove health parameters used.
- Total pressure scores were lower where mangrove health scores were higher, but not statistically correlated.
- There is no evidence to support the hypothesis that improved mangrove health leads to improved shellfisheries health.

Hypothesis 3

- Per capita food expenditure and shellfish income dependence were not related to any of the nutrition variables.
- Hb and anemia prevalence had significant correlations with income and wealth predictor variables that were opposite our expected direction.
- Dietary diversity score and dietary diversity adequate were positively correlated with the wealth-poverty score.
- The HFIAS score (a higher score means higher food insecurity) was negatively correlated with the household income rank and the wealth-poverty score.
- A food secure household was positively correlated with household income rank and the wealth-poverty score.

Hypothesis 4

- The mean household diverse food system score was higher where mangroves show the least improvement or show decline, and where median per capita food expenditure was lower which were opposite expectations.
- Sites with higher mean diverse food system scores have higher mean MDD-W scores, higher prevalence of households with adequate diets, higher mean income ranks and lower per capita food expenditures.

- Mean MDD-W and MDD-W adequate was higher where the mean years farmed was higher and where the number of visits to a local market weekly was higher, and lower where the mean distance to a local market and percent of female headed households were greater.
- Results suggest that households that are more experienced at farming and have more adults rely less on buying food and depend more on what they grow. In addition, results suggest higher household income in male headed households, households with more adults, where households are closer to local markets, and with more years of farming experience.
- There is weak evidence to support the hypothesis that reduced pressure and threats improves mangrove health.
- There is no evidence to support the hypothesis that increased shellfisher income or per capita food expenditure in shellfishing households will improve nutrition in shellfishing households.

Main conclusions form these findings for each hypothesis are below.

Hypothesis 1: There was evidence in this study that co-management and women's empowerment leads to improved shellfish stocks. There was little evidence that heathier shellfisheries result in higher shellfish consumption among women shellfishers, improved income, or lower poverty. There is no evidence that improved livelihood diversity improves shellfisher household income. Concerning the later conclusions, the cross sectional rather than time series research design, data collection methods, indicators used, and the small number of sites sampled in this study may have led to these negative findings. We recommend that those hypotheses not confirmed, regarding income and poverty, be further examined in subsequent studies. Other exogenous or local factors also may play a more important role.

Hypothesis 2: There was no evidence in this study that shellfisher protections or legal site protections (RAMSAR sites in these cases) improve mangrove health. This suggests potential weak or non-existent implementation of RAMSAR plans and that shellfisher efforts at protection are not sufficient to see changes in mangrove heath at the site level. Qualitatively, there was weak evidence that where pressures and threats were lower, mangrove health was higher. This aspect of the theory of change deserves further investigation. We recommend more detailed analysis and weighting for measuring severity of threats. The USAID guidelines for rating direct threats may provide a useful approach (USAID, 2017). We found no relationship between mangrove health and shellfish health even though the exiting scientific literature suggests a relationship between mangroves and fish yields (Aburto-Oropeza, 2008; Hutchison et al., 2014; Anneboina and Kumar, 2017). Again, future studies can improve the measures used in our study by factoring in overall mangrove area in relation to the number of shellfishers per unit of mangrove area and harvests per shellfisher, measures not used in this study. In addition, while mangroves may play a role, fishing effort, exploitation levels, and shellfish governance factors may be the overwhelmingly main drivers regardless of mangrove health. For example, Densu has few mangroves but a healthy and well-managed shellfishery. Tanbi has an abundance of mangroves and a healthy and well-managed shellfishery as well. Extent of mangrove habitat in an estuary may be more related to the overall potential total of shellfish yields at the site

rather than have any impact on exploitation levels. We did not assess this relationship in our study, but it has evidence in the scientific literature (Anneboina and Kumar, 2017).

Hypothesis 3: There was no evidence in our study that increased shellfish consumption decreases anemia levels. Low consumption levels of oysters by women shellfishers being the main reason. While oysters are a good source of iron and zinc, consumption levels would have to increase by a large amount to have any real impact. However, Adu-Afarwuah et al. (2022) advised not to promote increased consumption due to substantial health risks from heavy metal contamination in oyster tissues in Ghana sites, most notably of mercury. Government agencies should identify local sources of contamination and work to reduce heavy metal loading into the estuaries. This study did suggest that increased household income and greater wealth improves food security and having adequate dietary diversity, but unrelated to shellfish income. However, Adu-Afarwuah et al. (2022), using a different approach (Poisson regression and assessing each country separately), showed opposite results not supporting this hypothesis. Given the conflicting evidence depending on approach used, this hypothesis is worthy of further study.

Hypothesis 4: There was no evidence from our study that improving proximate landscape livelihoods reduces pressure and threats to mangroves or improves mangrove health. Our study suggests that increasing proximate landscape livelihoods increases household income but decreases per capita food expenditures due to more reliance on locally grown food and reducing the need to purchase food. Household characteristics can also influence nutrition, household income, and food expenditures. There was no evidence that higher household income or per capita food expenditure in shellfishing households improves MAHFP or dietary diversity. This is confusing with findings in hypothesis 3 which showed household income and wealth influenced other nutrition measures - the HFIAS score and being food secure. While the wealth measure was related to dietary diversity, household income and shellfisher income were not. Hence, while there were mostly negative findings on dietary diversity measures (except when using the wealth-poverty score) in the hypothesis 4 analysis, there was supporting evidence for the food security measures in the hypothesis 3 analysis. Chegini et al. (2021) have shown that food security in rural areas of Iran has complex associations with income, household welfare, and other household characteristics that are similar to our findings. Given the mixed results and complexity of relationships, more in-depth research is needed with respect to shellfishing household income, wealth, various nutrition measures, and other potential factors, with some factors having more influence than others.

1. INTRODUCTION

This report is a summary of a multivariate analysis of the theory of change model of the USAID Women Shellfishers and Food Security Project, which is a co-creation of the University of Rhode Island (URI) and partners from West Africa – the University of Cape Coast (UCC) in Ghana, the University of Ghana (UG), TRY Oyster Women's Association (TRY) in The Gambia, World Agroforestry (ICRAF), and the US Agency for International Development (USAID). This project seeks to address the need for greater attention to food security for women shellfishers and their families while improving biodiversity conservation of the ecosystems on which their livelihoods depend. The key project components are to:

1) *Conduct the first-ever participatory regional assessment of the situation, unmet needs, and promising approaches to shellfish co-management led by women across the eleven countries in West Africa.*
2) *Elaborate and test elements of models based on existing approaches through site-based research in The Gambia and Ghana to strengthen the evidence base for successful elements of the model.*
3) *Foster a community of practice around the development and dissemination of a toolkit on a rights-based, ecosystem-based, participatory co-management of shellfish by women in mangrove ecosystems in West Africa.*

This report is on *Sub-Activity 2f: Coordinate a theory of change review, data gathering, and multivariate analysis.* URI, ICRAF, UG, and UCC coordinated the development of a theory of change model of an integrated approach to women-led shellfish management, mangrove management, and food and nutritional security in the proximate land-seascape. We collected data from six field sites in two countries (Ghana and The Gambia) and used the data to assess several hypotheses in the theory of change model. As part of the documentation of the evidence base, we summarize whether findings support or are counter to hypothesized assertions. We discuss limitations of the study as well.

1.1. The Initial Theory of Change Model and Associated Hypotheses

The Women Shellfishers and Food Security program description (USAID, 2020) posited an initial theory of change model shown in Figure 1 below. The theory of change describes the interrelationship between women's empowerment, sustainable shellfisheries management, and cross-sectoral linkages to community-based mangrove conservation, local food system livelihoods, and nutrition of shellfishing households. The theory of change statement is:

IF women's shellfish livelihoods in coastal mangrove and estuarine ecosystems in The Gambia and Ghana are improved through gender and nutrition sensitive co-management and linkages made to community based forest management in the land/seascape, THEN mangrove and estuarine biodiversity will be improved, AND IF approaches for sustainable food producing livelihoods within the coastal mangrove land/seascape contribute to a nutritionally balanced local food supply, THEN household resilience, sustainable food systems, and nutrition will improve.

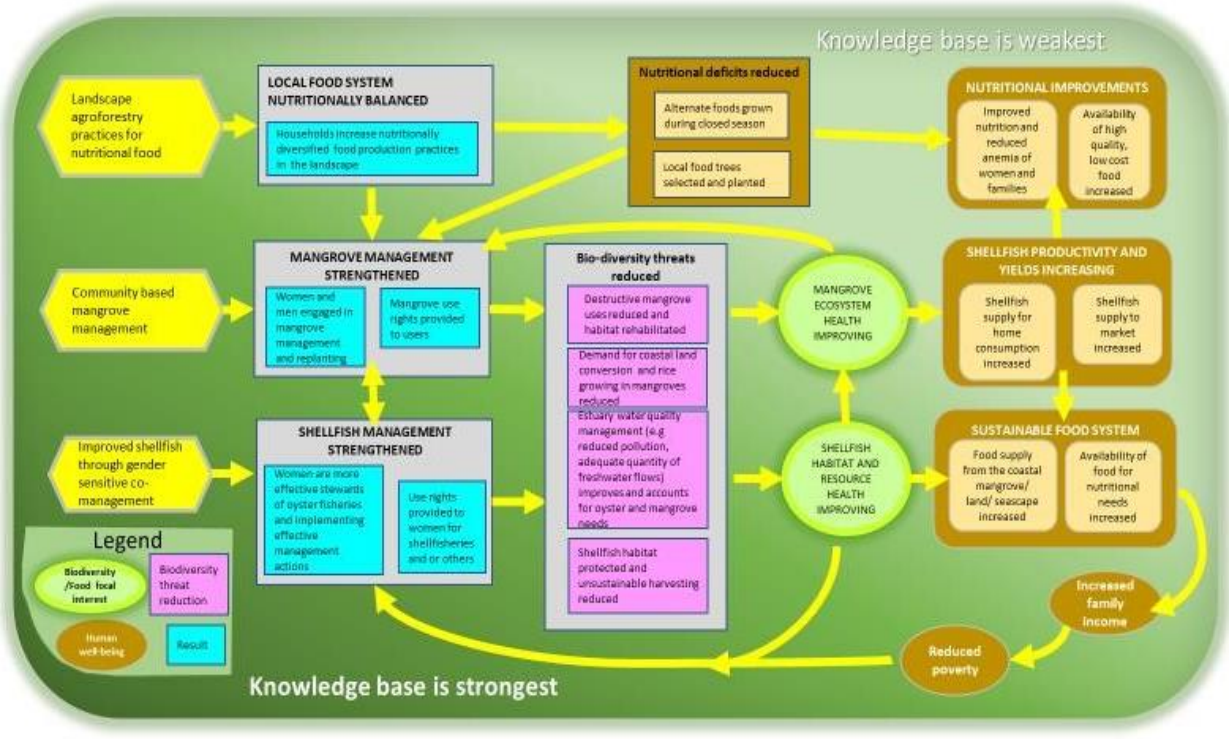

Figure 1: Visualization of the Theory of Change and Results Chain Framework.

The theory of change was further broken down in the program description into several testable and interlinked hypotheses as stated below.

1. Gender sensitive governance that promotes co-management and tenure rights and empowered women that manage shellfisheries sustainably improves conservation of mangroves.
2. Improved and gender equitable management of shellfisheries and mangroves increases shellfish yields and availability of this nutrient rich food protein, which increases shellfish consumption and contributes to improved household nutrition and income of those engaged in shellfishing.
3. High consumption of shellfish contributes to lower prevalence of anemia in women of reproductive age and is a main contributor compared to other factors such as malaria or hookworms.
4. Enriching landscapes around mangrove-shellfish estuaries systems with complementary food and nutrition sources reduces the extractive pressure on the mangroves thereby improving its health which subsequently boosts the productivity of the shellfishery having direct impact on household food security.

1.2. Review of the Evidence Base and Literature

Our theory of change model is based on practitioner experiences and qualitative evidence of these interrelationships. It stitches together several sector-based models into a broader integrated theory. To our knowledge, no in-depth studies have provided a solid evidence base of this integrated theory. Our focus is on women shellfishers in West Africa, an "invisible fishery" that is poorly documented but makes substantial contributions to food security and employment through their harvests (Chuku, et al., 2022a). These women, therefore, have the potential to play a significant role in sustainable fisheries management and conservation of associated biodiversity and the mangrove and estuarine systems on which their livelihoods depend. Of particular interest are the cases from Ghana (MOFAD, 2020) and The Gambia (MFWR, 2012), where government granted use rights to women shellfishers and have been successfully implementing co-management plans for estuarine shellfisheries for several years. These women have implemented annual shellfishing closed seasons, established minimum size limits for shellfish, replanted and promoted natural regeneration of mangroves, and protect them from cutting.

Co-management of mangroves (Datta et al. 2012; Aheto et al., 2016; Damastuti et al., 2022) and fisheries (d'Armengol et al., 2018; Hilborn et al., 2020; Melnychuk et al., 2021) are effective at improving sustainable management of these resource systems and are well documented in the existing knowledge base. Crawford et al., (2010) documented successful examples of community-based women-led co-management of cockles in Nicaragua and Tanzania. Anderson and Seijo (2010) explain the theoretical connections between sustainable fisheries management and fisheries revenues and hence fisher income, but Teh et al., (2020) has shown there is little documentation about income levels among small scale fishers.

Our research activities looked at the connections between fisheries management, resource tenure, and mangrove conservation. There is good evidence showing linkages between mangrove area and fisheries yields (Aburto-Oropeza, 2008; Hutchison et al., 2014; Anneboina and Kumar, 2017), but less evidence connecting co-management of mangroves to fisheries health (exploitation levels). Our research further investigates the broader community-based resource management aspects of the model and the mangrove – fisheries management linkages.

Swindale and Belinski (2006) assert that a more diversified diet is associated with improved hemoglobin concentrations and is highly correlated with household income, and that in extremely poor households, increased food expenditure resulting from additional income is associated with increased quantity and quality of the diet. This study more specifically examined the connections between coastal food systems, oyster consumption and nutritional wellbeing of women shellfish harvesters and their households. This component of the model is less well proven and where the evidence base is weak. However, it is well documented that oysters are a good source of iron and zinc, where one 100g serving of raw oysters provides 100 percent of the Recommended Dietary Allowance (RDA) for zinc and 26 percent of the RDA for iron for women of reproductive age (IOM

2011). What is not known is the extent to which women shellfishers who consume part of their catch of oyster and cockles may suffer less anemia due to oyster consumption.

For more information and summaries on the exiting literature concerning the various aspects of our integrated theory of change model, see the site-based research technical reports produced by the Women Shellfishers and Food Security Project. The full citations and hyperlinks to the documents include:

- Duguma, L., Bah, A., Muthee, K., Carsan, S., McMullin, S., Minang, P. (2022). Drivers and Threats Affecting Mangrove Forest Dynamics in Ghana and The Gambia. USAID Women Shellfishers and Food Security Project. World Agroforestry (ICRAF), Kenya. WSFS2022_01_CRC.
- Duguma, L., Darko Obiri, B, Carsan, S., Muthee, K., Tang Guuroh, R., Antwi Oduro, K., Mcmullin, S., Duba, D. (2022). Participatory Land-Seascape Visioning in Densu Estuary, Narkwa Lagoon, and Whin Estuary, Ghana. USAID Women Shellfishers and Food Security Project. World Agroforestry (ICRAF), Kenya. and CSIR-FORIG, Ghana. WSFS2022_02_CRC.
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- Adu-Afarwuah, S., Kyei-Arthur, F., Ali, Z., Oaks, B. (2022). Dietary Intakes, Food Security, and Anemia Prevalence among Women Shellfishers in Selected Estuary Sites in Ghana and The Gambia. USAID Women Shellfishers and Food Security Project. University of Ghana Department of Nutrition, Ghana and University of Rhode Island Department of Nutrition and Food Science, USA. WSFS2020_06_CRC.

2. METHODOLOGY

2.1. Site Selection

The research design called for data collection in six estuarine sites, three in each of two countries (Ghana and The Gambia) to assess aspects of the theory of change. We used purposive sampling to select the final sites since the characteristics of the entire population of estuaries where women shellfishing occurs regionally are not well known. We collected secondary and qualitative field information on candidate field sites in Ghana and The Gambia where shellfishing takes place. Sites selected had significant variation in key outcome variables such as fisheries and mangrove health, and treatment variables such as governance, gender dimensions, and women's empowerment. Criteria used to select the final sites from the candidate list of sites developed in each country are as follows:

- Existing shellfishing activity,
- Significant involvement of women shellfishers,
- Existing mangrove systems-based livelihoods,
- A range of healthy, moderately, and unhealthy biophysical status of the mangroves and degradation rates over time,
- A range of shellfish governance arrangements.

From the initial candidate sites surveyed, the three estuarine sites selected in each country were:

- Ghana: the Densu, Narkwa, and Whin estuaries
- The Gambia: the Tanbi, Allahein, and Bulock estuaries

For a more detailed description of the site selection process see Chuku et al. (2020).

2.2. Refinement of the Model and Associated Hypothesis

We refined the original program theory of change included in the program description (Figure 1) into a more simplified model for the statistical analysis. The simplified version shows unidirectional relationships and does not include any feedback loops as shown in the original theory of change. URI developed a simplified version of the theory of change which partner team members then reviewed. We then developed a consensus-based model for the multivariate analysis.

2.3. Data Collection at the Field Sites

Program Partners - ICRAF, UCC, and UG - collected field data as part of their respective site-based activities in each of the six field sites. Multivariate analysis used the compiled data.

The study used a mixed methods approach, collecting qualitative information and local knowledge through focus group discussions and key informant interviews, expert knowledge of the researchers, and quantitative data collected from random samples of individual shellfishing households at each of the six sites. Bio-physical information for each site was also collected over a one year period.

The University of Ghana collected individual and household level data on anemia, nutrition, food security, socioeconomics, and food systems of shellfishers and their households, and on women's empowerment. Sample size varied across sites based on the number of women shellfishers at each site. We did not achieve the initial target of sampling 200 women of reproductive age per site and households as most sites had fewer shellfishers than initial estimates indicated.

UCC collected site level data on biophysical indicators such as current state of shellfish and mangrove resource conditions and trends. Data on governance of shellfisheries and mangroves, and on nutritional adequacy of local food production systems in the landscape adjacent to the estuaries of communities using mangroves and shellfish, used expert opinion of partner team members, as well as information from focus group discussions and key informant interviews.

We created constructed scales for some variables using data from both individual and household surveys as well as from expert opinion. Specifically, we collected data on eight different aspects of inquiry for empirical testing of the theory of change:

(1) Mangroves: Site based mangrove system characteristics were assessed indicating the health of the mangroves in terms of the rate of deforestation. Spatiotemporal retrospective of changes in mangrove cover using existing satellite imagery (2000-2010-2020) and geospatial analyses, as well as in-situ identification of drivers and threats. Local ecological knowledge was used to understand the drivers and threats. Sites were ranked into high, medium, and low levels of mangrove health based on expert opinion and total pressures and threats scores calculated by summing several categories as high, medium, and low per site.

(2) Shell fishery: Fishing mortality and exploitation ratios were calculated based on length frequency data of oysters in each site. A fisheries health index was also used based on fishing mortality and exploitation ratio values. Mean shellfish height per site was also used as a fisheries health indicator.

(3) Water quality: Physicochemical parameters that could influence shellfish health were collected at each site. These included salinity, temperature, Dissolved Oxygen (DO), estuary depth, pH, and turbidity.

(4) Landscape level and household food systems: Measures of the totality and adequacy of food grown in the landscape adjacent to the mangrove and shellfishing estuaries in providing access to or local availability of a nutritionally balanced diet were used. A MAHFP scale was developed on the degree of livelihood and food system diversity in the household based on questions in the ICRAF household survey. Other characteristics of the household such as household demographics, distance to local markets, frequency of visits to local markets, etc. were collected in the ICRAF household survey.

(5) Governance: Governance dimensions at the site level were assessed for mangrove and shellfishery management and ranked as presence or absence of active co-management, traditional management, use rights, and protected area status. Total governance scores per site were calculated summing the individual governance scores.

(6) **Gender empowerment:** We constructed scale of the level of women shellfishers empowerment based on five domains described by IFPRI (2012). The women's empowerment score was calculated based on responses to questions incorporated into the socio-economic survey of women shellfishers. While based on the Women's Agricultural Empowerment Index (WEAI), the questions used were shortened and tailored to the context for women shellfishers (see IFPRI, 2012 and Alkire et al., 2013 for more information on WEAI). Ragsdale et al., (2022) used a similar approach for exploring gender equity among fisherfolk in Zambia.

(7) **Socio-economics of shellfishers:** We used data on level of income and dependence on shellfishing for livelihood, as well as individual and household characteristics from the UCC survey and per capita food expenditures of adults in the shellfishing household from the ICRAF survey.

(8) **Nutrition**: We used data on anemia in women of reproductive age (hemoglobin concentration using HemoCue devices), household food insecurity using the Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2007), and a 24 hour dietary recall conducted on two non-consecutive days that captured total oyster consumption and all sources of zinc and iron in the women's diet to determine percent of total iron and zinc consumption coming from oysters. We also used the Minimum Dietary Diversity for Women (MDD-W) (FAO, 2016)

Table 1 below summarizes the type of data collected, type of survey, and the partner group collecting the data. The actual sample sizes for the various types of data used in this study are shown in the analysis section of this report in relation to the statistical reporting.

Table 1: Type of data collected, survey types, and partners.

Type of data	Survey type(s)	Partner collecting data
Mangroves	Site level, FGD, KII	ICRAF
Shellfishery biological parameters	Site level, 6 sampling stations per site, data collected monthly for 1 year	UCC
Water quality	Site level, 6 sampling stations per site, data collected monthly for 1 year	UCC
Landscape level and household food systems	FGD, Individual and household	ICRAF
Governance	Site Level	UCC, ICRAF
Gender empowerment	Household survey	UCC
Socio-economics	FGD, KII individual and household	UCC
Nutrition and anemia	Individual and household	UG

For more information on the site-based research methods and analysis, see the site based technical reports of each of the partners listed in Section 1.2 above (Adu-Afarwuah, et al., 2022; Chuku et al., 2022; Duguma, et al., 2022; Carsan, et al., 2022).

Individual and household survey instruments and semi-structured interview guides are in Appendix 1. A full list of variables and constructed variables is in Appendix 2. The URI Institutional Review Board (URI-IRB) approved this research as well as by country level institutional review boards where appropriate. We obtained informed consent from each person interviewed or involved in focus group

discussions. COVID-19 protocols were followed as required by the URI – IRB as the field work took place during the initial years of the global pandemic.

For data collection at the individual and household level, questionnaires were developed and deployed using Kobotoolbox, a free and secure web-based, paperless data collection and storage system. Survey instruments were deployed using a phone, tablet, or computer device. Local enumerators collected data using local languages of the interviewees, and responses stored on the device until linked to the internet via a cellular, Wi-Fi, or cable connection, where it was then automatically uploaded to the cloud-based storage site and no longer stored on the tablet. Data was then downloaded from the cloud-based storage in Excel or other electronic format for data review, cleaning, and finalization for analysis.

Below are the periods for data collection by the various partners:

- University of Ghana: June – July, 2021; 718 households surveyed.
- UCC: August – December, 2021 (household surveys and FGDs); 120 households surveyed.
- ICRAF: May – August, 2021 (household surveys and FGDs); 356 households surveyed.

2.4 Statistical Analysis

We used Excel, SPSS, SAS, and R software for statistical analysis. The type of analysis was determined based on the type of data and included both parametric and non-parametric tests of statistical significance.

Different partner organizations conducted household-level surveys in different households at different times within the same site. As such, we could not align information from two different surveys for certain types of analyses. Consequently, it was not possible to assess relationships between variables from different surveys at the household level or do more complex multiple regression techniques by combining data from the different surveys. Instead, we aggregated data at the site level using the mean (or median for highly skewed distributions) of household level information within the site. We then assessed site level relationships using spearman correlations and descriptive analyses.

In cases where household or individual-level information was available for the variables of interest we assessed the relationship using linear or logistic regression controlling for country to account for regional differences in the outcome while using cluster-correlated robust estimates of variance (Froot, K. A., 1989) to account for the dependence in observations within a site.

We used a confidence level of 90 percent ($P < 0.10$) and 95 percent ($p < 0.05$) for reporting statistical significance due to small sample sizes for the site level analysis ($n = 6$ sites) and number of clustered groups (6 sites for case level analysis).

3. RESULTS AND DISCUSSION

3.1. The Refined Theory of Change Model and Associated Hypotheses

The path model below (Figure 2) is a more simplified and modified version of the Women Shellfishers and Food Security program description theory of change (Figure 1) based on roundtable discussions with partner team members. The original theory of change shows the complexity of interactions between several interventions and subsequent outcomes. For purposes of developing a statistical approach and data gathering for assessing the theory of change, this more simplified version of the model was used for the multivariate analysis.

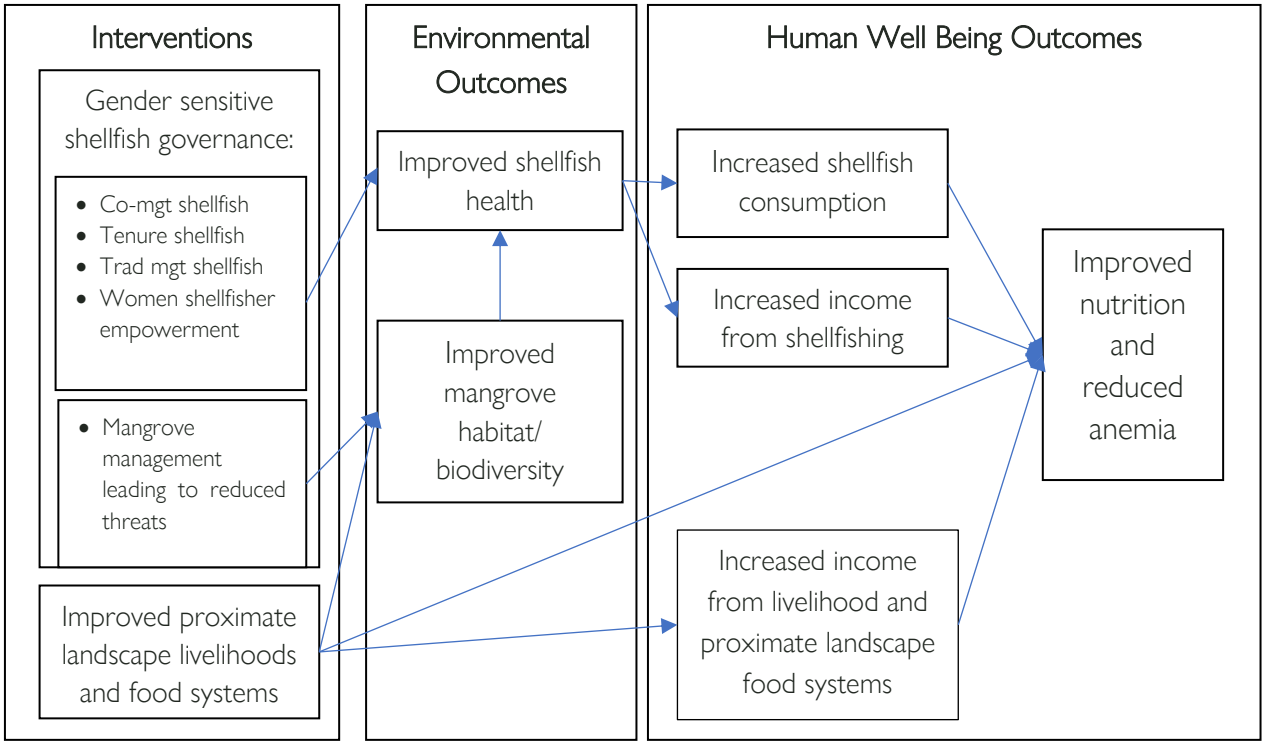


Figure 2: Overall path model (theory of change) showing causal links of interventions with environmental and human well-being outcomes.

We modified the original four hypothesis statements (subsets of the overall theory of change) in the program description in consultation with partner team members into more simplified causal change statements (sub-theories or complex hypotheses), and to prevent duplication between the four hypothesis statements of IF-THEN hypotheses (arrows in the figure above). The four modified hypotheses are:

Hypothesis 1. Improved and gender equitable management of shellfisheries increases shellfish yields, which increases shellfish consumption and income of those engaged in shellfishing.

Hypothesis 2.-Shellfisher mangrove management actions improve mangrove habitat which in turn improves the health of shellfish stocks.

Hypothesis 3. High consumption of shellfish and increased income from shellfishing contributes to lower prevalence of anemia in women of reproductive age and improves other nutrition variables. Shellfish consumption is a main contributor to reduced anemia compared to other factors such as geographic factors or household and individual characteristics.

Hypothesis 4. Enriching landscapes around mangrove-shellfish estuaries systems with complementary food and nutrition sources reduces the extractive pressure on the mangroves thereby improving mangrove health and improves shellfisher household income and household food security.

Figure 3 below shows how the four final hypothesis statements each cover a different part of the overall path model.

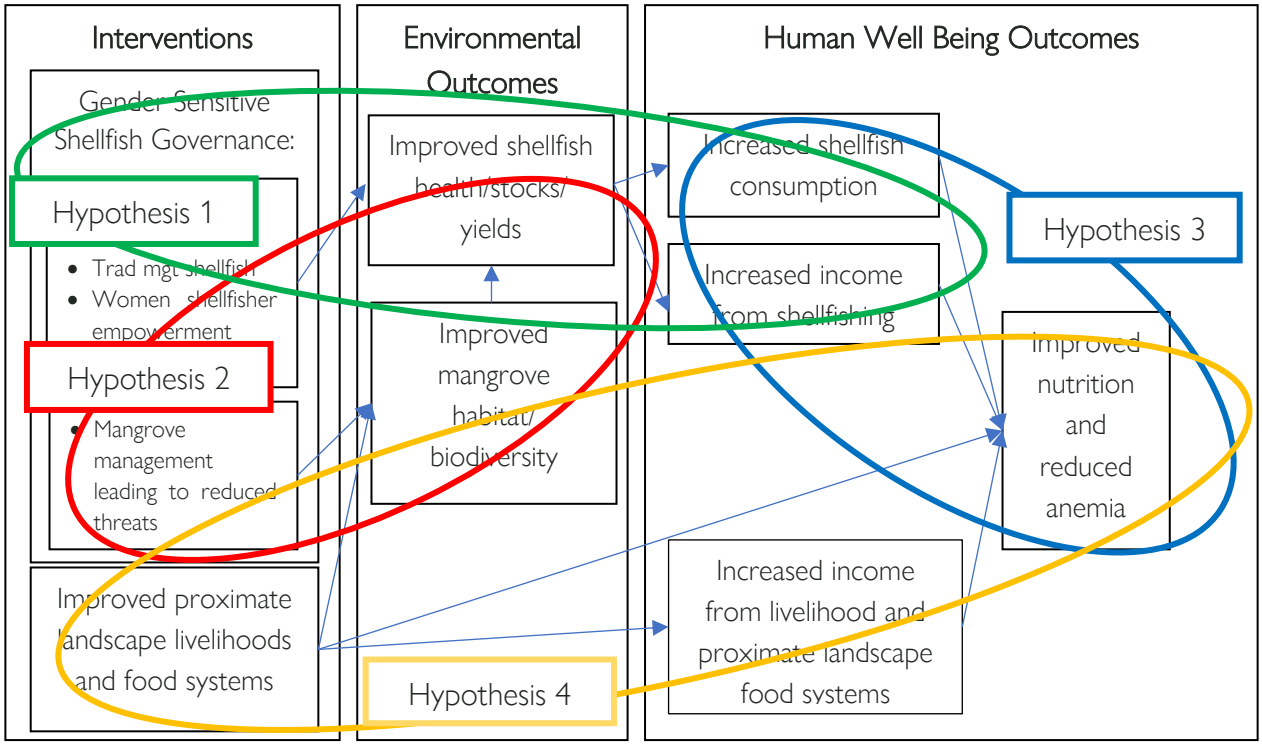


Figure 3: Path model overlaying the four hypotheses modified from the program description.

Each sub-theory or complex hypothesis was further broken down into individual testable IF-THEN or IF AND IF - THEN statements (simple hypotheses) for construction of statistical models and subsequent analysis. The specific simplified IF-THEN statements for each of the four hypothesis statements is shown in the following sections.

3.2. Hypothesis 1: Shellfisheries Management, Health, Consumption, and Income

Hypothesis 1: Improved and gender equitable management of shellfisheries increases shellfishery health, which increases shellfish consumption and income of those engaged in shellfishing.

The causal path model for hypothesis 1 is shown in Figure 4 below.

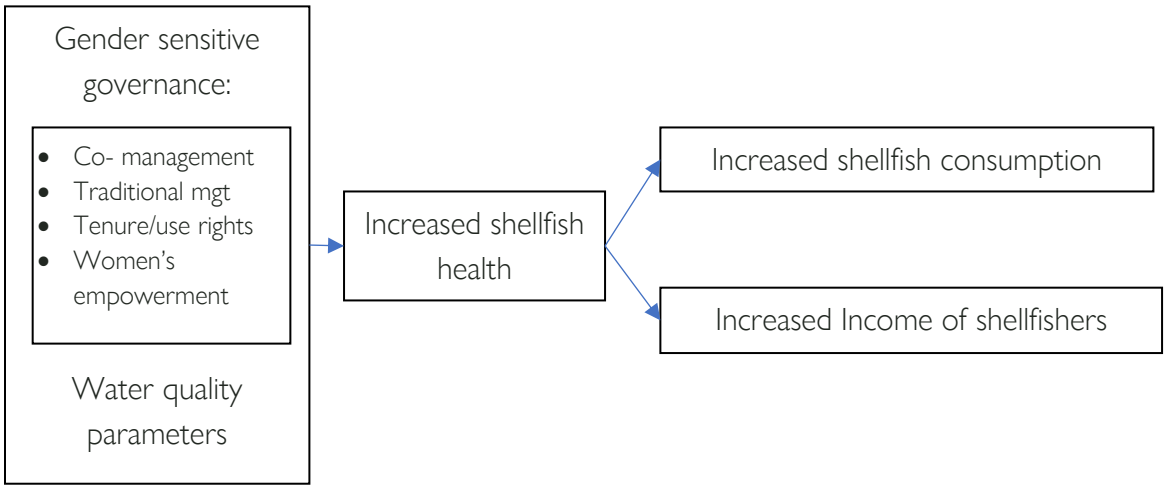


Figure 4: Casual path model for hypothesis 1.

The causal paths of IF – THEN statements represented by the arrows in the figure above are:

- IF gender sensitive governance (co-mgt + tenure + trad mgt + women's empowerment) + water quality THEN increased shellfish health/yields
- IF increased shellfish health, THEN increased consumption
- IF increased shellfish health, THEN increased income

The simple model equations for predictor and outcome variables are shown below:

- Increased shellfish health = gender sensitive governance + water quality + country + site
- Increased shellfish consumption = increased shellfish health + country + site
- Increased income = increased shellfish health + country + site
- Gender sensitive governance = co-mgt + tenure + trad mgt + women's empowerment

Governance and Shellfishery Health

A primary component of our theory of change model is that improved governance will improve the health of the shellfish resource. Table 2 below shows the range of governance scores and several

measures of the status of the shellfish resource at each site (for definition and scoring of variables, see the Appendix 2). There seem to be no differences between countries as each country has a similar range of governance scores and fisheries health status across sites.

Table 2: Fisheries governance and shellfish health per site.

Country	Site	Co-mgt present	Resource tenure (use rights) present	Traditional mgt present	Total Governance Score	Fishing Mortality	Exploitation Ratio	Fisheries Health	Fisheries Health Rank	Fisheries Health Dichotomized
Ghana	Densu	1	1	1	3	0.07	0.04	underexploited	2	underexploited
Ghana	Narkwa	0	0	0	0	1.65	0.50	overexploited	0	fully or overexploited
Ghana	Whin	0	0	0	0	0.8	0.29	fully exploited	1	fully or overexploited
The Gambia	Tanbi	1	1	1	3	0.04	0.05	underexploited	2	underexploited
The Gambia	Bulock	0	0	1	1	2.56	0.59	overexploited	0	fully or overexploited
The Gambia	Allahein	0	0	1	1	0.59	0.28	fully exploited	1	fully or overexploited

The following charts (Figures 5, 6, 7) show the relationship of the fisheries health status measures per site versus the total governance score per site. The shellfish exploitation ratio tends to decrease as the governance score increases (Figure 5). Fishing mortality shows a similar trend (related to the exploitation ratio) which tends to decrease as the governance score increases (Figure 6). Fisheries health rank, which is based on fishing mortality and exploitation ratio ranges (see Appendix 2 for indicator definitions and scoring) tends to increase as the governance score increases (Figure 7). The trends are all in the expected direction, and statistically significant at the $p>0.10$ or $p>0.05$ level, supporting the hypothesis that better governance improves shellfishery health. Since the sample size is small for any robust statistical analysis (N=6), we report significance at the $p < 0.10$ level in addition to at the $P < 0.05$ level.

Governance scores of 0 and 1 tend to show few differences between the measures of shellfishery health status (exploitation ratio, fishing mortality, fishery health rank), whereas sites with a governance score of 3 tend to be very different on all measures compared to sites with a governance score of either 1 or 2. Sites with governance scores of 3 include the Densu Delta in Ghana, and the Tanbi Wetland in The Gambia; both with strong governance arrangements that include formal co-management and use rights, as well as support from traditional authorities. These two sites also have closed seasons for five to eight months of the year which helps explain the low fishing mortality, exploitation ratio, and underexploited status of the resource.

> Sites with a higher governance score have a lower exploitation ratio and fishing mortality, and higher fishery health rank compared to sites with a lower governance score.

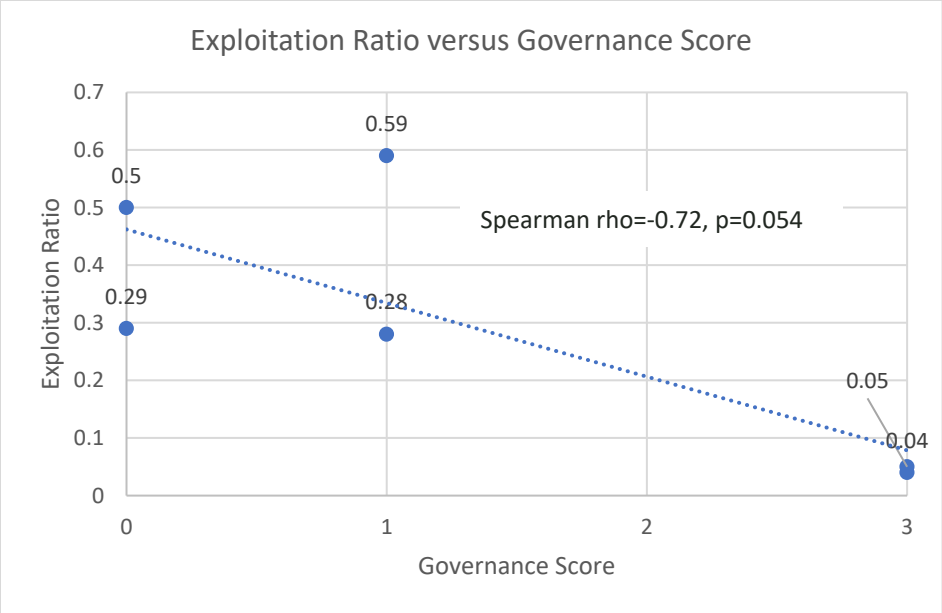


Figure 5: Relationship between site level exploitation ratio versus governance score.

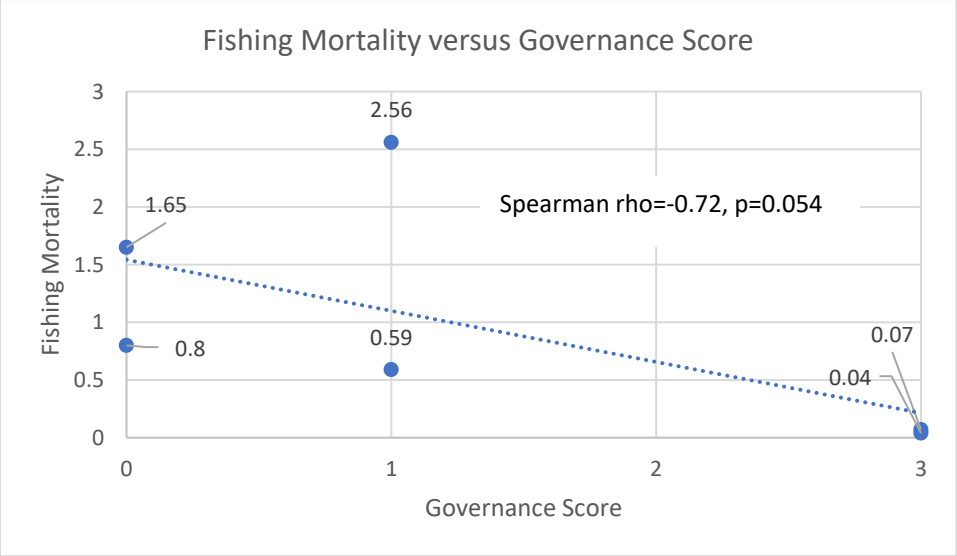


Figure 6: Relationship between site level fishing mortality versus governance score.

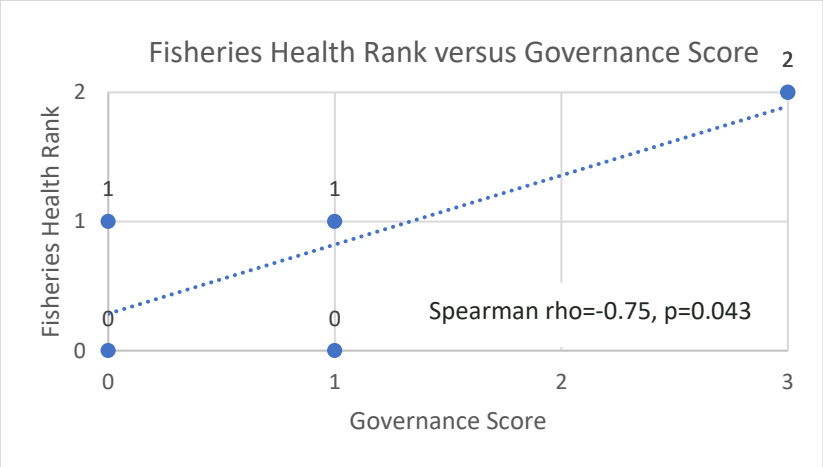


Figure 7: Relationship between site level fisheries health rank and governance score.

Shell height, another fisheries health proxy indicator (we assumed greater shell height is a healthier shellfish stock), is significantly related to governance scores (case level regression analysis controlling for site clustering and country as a factor, (Model: Shell height = intercept + country + total governance score: R^2 = .073, χ 2 (1,N=4201) = 2.85, p = .09). Shell height is greater in sites with higher governance scores (Figure 8).

Shell height - a shellfisheries health indicator - is greater in sites with a higher governance score.

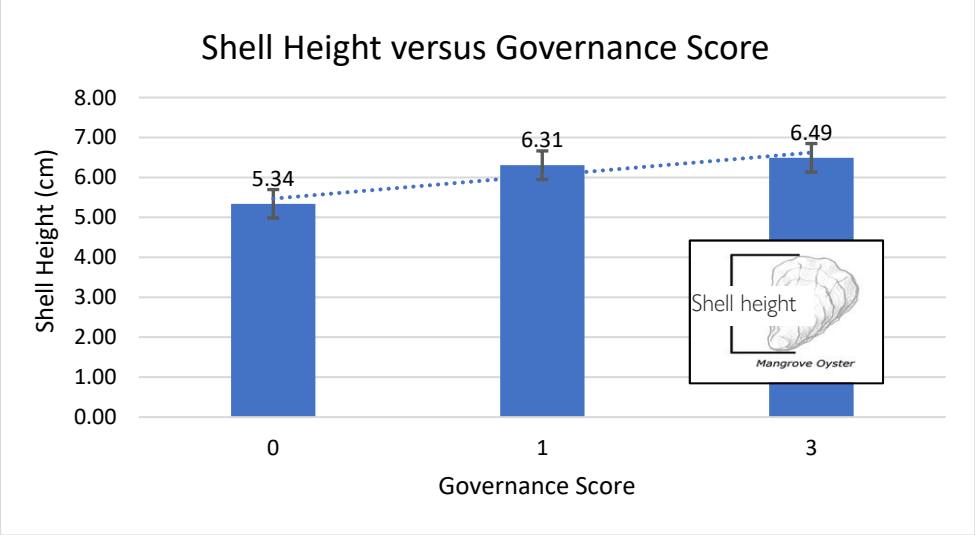


Figure 8: Shell height versus governance score.

Site level analysis of mean shell height per site and governance scores (Spearman rho=0.84, p = 0.019, 1-tailed) shows a strong positive correlation of a higher mean shellfish height with a higher governance score (Figure 9).

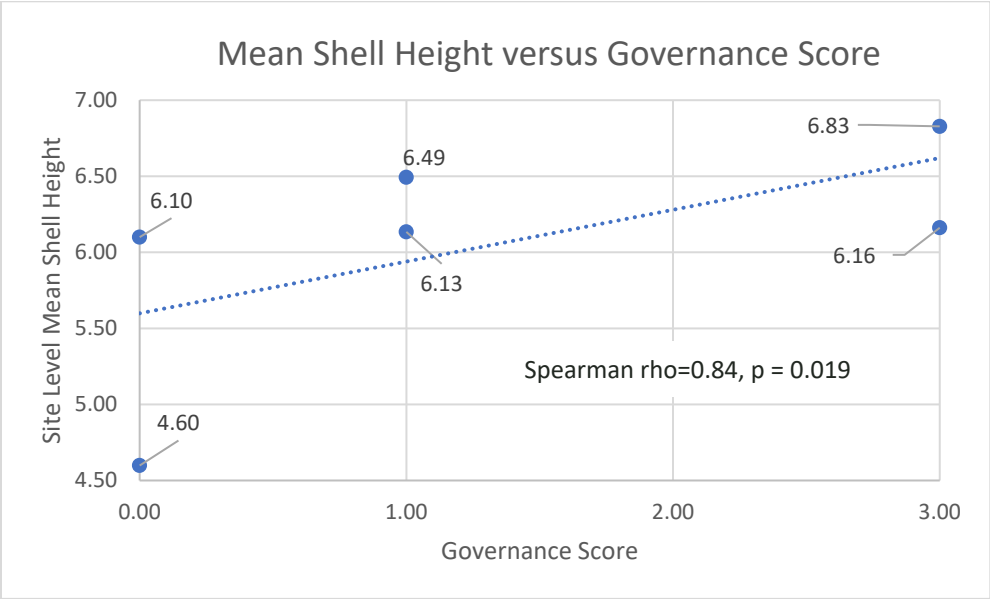


Figure 9: Relationship between mean shell height per site and site governance score.

Women's Empowerment and Shellfishery Health

Our theory of change model also asserts that in addition to improved governance, women's empowerment will improve health of the shellfishery. While women's empowerment is an ordinal scale, it has a large enough range to be treated as continuous data, and thereby allow use of parametric statistics.

Differences between the women's empowerment score and shellfish health rank the exploitation ratio and fishing mortality are statistically significant ($p < 0.05$) using linear regression with data clustered at the site level and controlling for country as a factor. The models below explain about one-fourth to one-third of the variance between the fisheries health variables and the women's empowerment score.

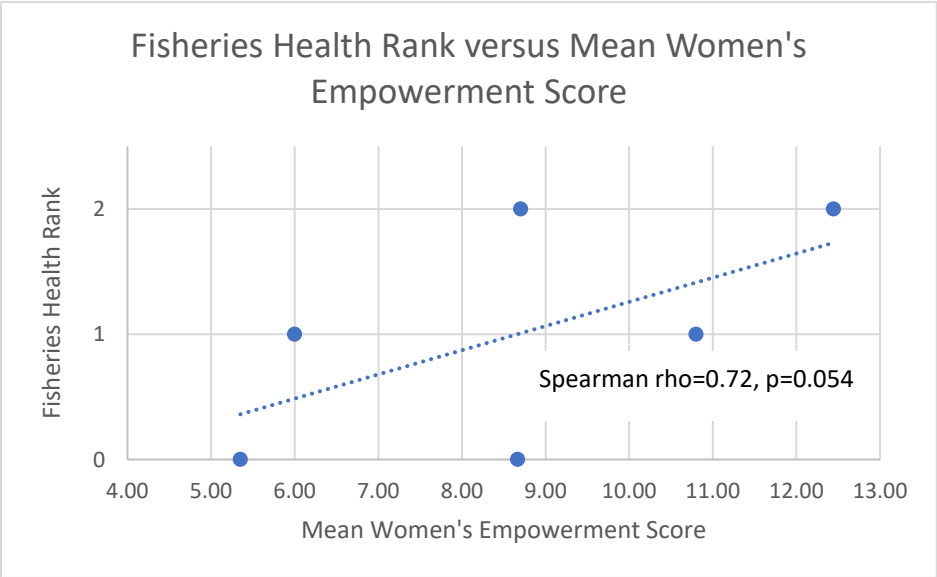
Model: Fisheries health rank = Intercept + Country + Women's empowerment, $R^2 = .363$, $\chi 2\ (1,N=103) = 6.77$, $p = .01$;

Model: Exploitation ratio = Intercept + Country + Women's empowerment, $R^2 = .343$, $\chi 2\ (1,N=103) = 6.63$, $p = .01$;

Model: Fishing mortality = Intercept + Country + Women's empowerment, $R^2 = .234$, $\chi 2\ (1,N=103) = 5.42$, $p = .02$.

Fisheries health rank is greater, and exploitation ratio and fishing mortality lower, where women's empowerment scores are higher.

Figure 10 below shows the statistically significant relationship ($p < 0.10$, 1-tailed) and strong correlation between the women's empowerment score and fish health rank. As the women's empowerment score increases, the fisheries health rank also tends to increase.



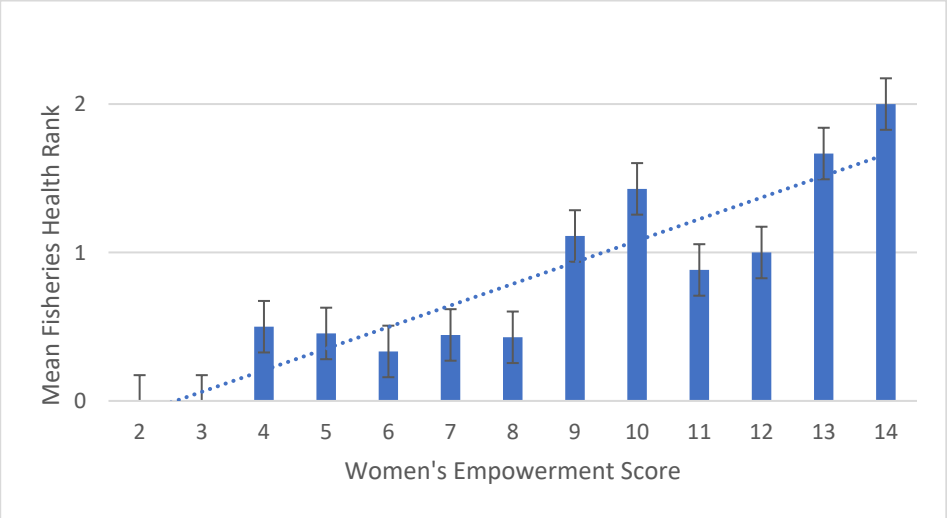
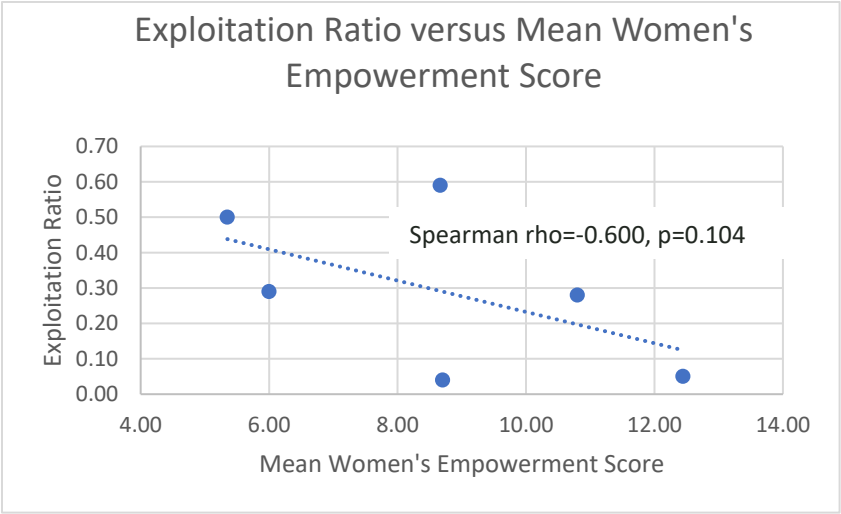


Figure 10: Plots of mean by fisheries health rank by women's empowerment score.

Figure 11 shows a moderate correlation between the mean women's empowerment score per site and the exploitation ratio per site. Higher women's empowerment scores have lower exploitation ratios but this is not a statistically significant result ($p < 0.10$, 1-tailed).



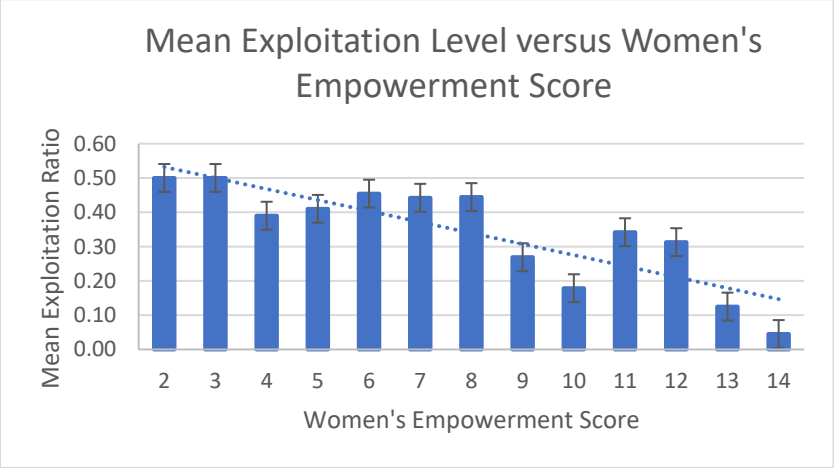


Figure 11: Plots of mean exploitation ratio by women's empowerment score.

Figure 12 shows the relationship between mean women's empowerment score per site by mean shellfish height per site. Higher women's empowerment scores have greater mean shell height. Using site level analysis of mean values per site (N=6) and non-parametric statistics (Spearman correlation) shows mean shell height as significantly and strongly correlated with the women's empowerment score at the $p < 0.05$ level (1-tailed).

Mean shell height is higher where women's empowerment scores are higher.

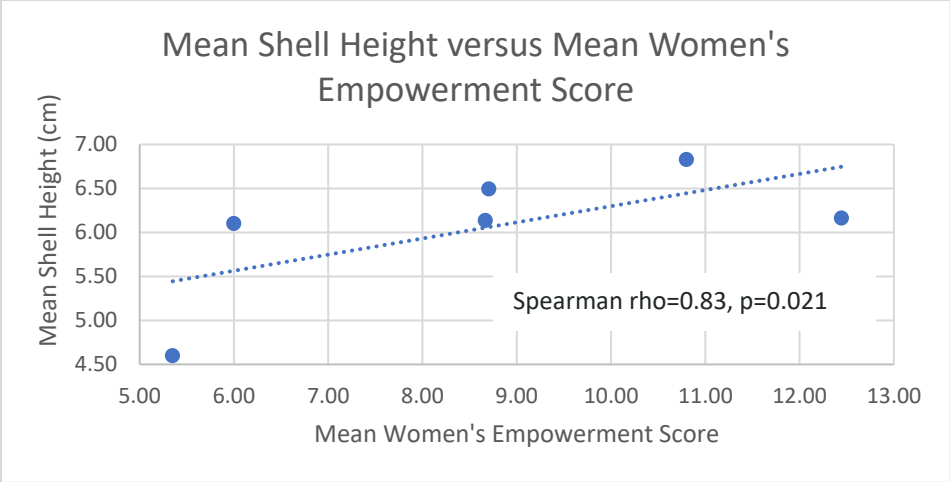


Figure 12: Plot of mean shell height versus mean women's empowerment score.

Figure 13 shows a statistically significant ($p < 0.10$, 1-tailed) moderate correlation between fishing mortality and the mean women's empowerment score per site. Fishing mortality is lower where women's empowerment scores are higher.

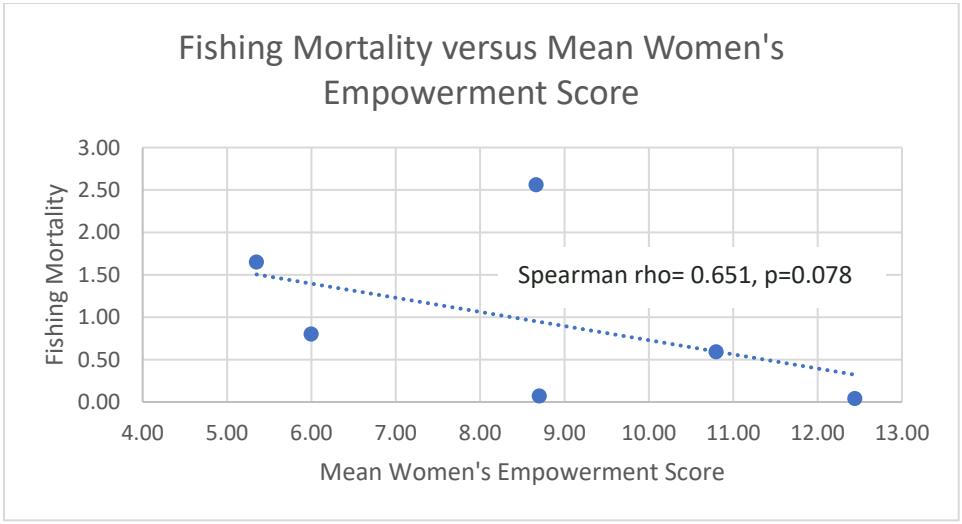


Figure 13: Plot of fishing mortality by mean women's empowerment score.

These results support the hypothesis that women's empowerment improves shellfishery health.

Physico-chemical Parameters and Shellfishery Health

Our model suggests that in addition to improved governance and women's empowerment, certain physico-chemical parameters could influence shellfishery health. For instance, low dissolved oxygen can slow growth or inhibit reproduction of oysters. Similarly, extremely low or extremely high salinity can affect oyster growth and survival within an estuary or lagoon. High turbidity can also be

detrimental to oyster survival and growth. Table 3 shows the mean values of data collected monthly over 12 months and for each country and site for temperature (^{0}C), dissolved oxygen (DO), salinity (ppt), pH, depth (meters) and turbidity (NTU). We also use mean shell height (in cm. for oysters) as a measure of shellfishery health.

Table 3 shows the mean values for the physico-chemical parameters and for shell height. All are statistically significantly different (ANOVA, $p<0.05$) between countries and between sites except dissolved oxygen at the country level. For those that showed statistically significant differences, all showed a medium or large effect size except for dissolved oxygen at the site level and shell height at the country level (small effect). While there is significant variation among the six sites, it is interesting to note that between countries, the characteristics of the oyster estuarine habitats vary on all parameters. Ghana sites have a higher mean temperature, pH, turbidity and a lower mean depth and salinity. Ghana sites also have a shorter mean shell height, which implies that the Ghana estuarine physico-chemical characteristics result in smaller oysters.

Ghana sites have a higher mean temperature, pH, turbidity and a lower mean depth and salinity, as well as a shorter mean shell height than sites in The Gambia.

Table 3: Mean physico-chemical parameters and shellfish height per country and per site.

Country/Site	Shell Height (cm)	Temperature (^{0}C)	DO (ug/l)	Salinity (ppt)	pH	Depth (m)	Turbidity (NTU)
Mean values of site physico-chemical parameters by country							
Ghana	5.84	29.14	5.53	19.37	8.02	0.72	28.21
The Gambia	6.26	28.22	5.38	33.19	7.52	2.72	6.52
ANOVA results							
N	4200	1152	957	1146	941	1152	1003
df	1	1	1	1	1	1	1
F	70.96	45.52	1.97	468.23	162.20	877.34	225.78
p	<0.001	<0.001	0.161	<0.001	<0.001	<0.001	<0.001
Eta-squared	.017	.038	.002	.290	.147	.433	.184
Mean values of site physico-chemical parameters by site							
Densu	6.83	29.09	5.40	18.57	7.93	0.70	19.46
Narkwa	4.60	28.81	5.45	19.60	8.05	0.83	27.41
Whin	6.10	29.51	5.75	19.97	8.07	0.63	38.63
Tanbi	6.16	28.11	5.22	34.20	7.46	2.97	5.91
Bulock	6.49	28.80	5.16	30.32	7.50	2.93	5.93
Allahein	6.13	27.80	5.73	34.83	7.59	2.27	7.67
ANOVA results							
n	4200	1152	957	1146	941	1152	1003
df	*5*	*5*	*5*	*5*	*5*	*5*	*5*
F	*412.91*	*14.85*	*3.20*	*99.22*	*34.43*	*192.71*	*60.996*
p	<0.001	<0.001	0.007	<0.001	<0.001	<0.001	<0.001
Eta-squared	*.185*	*.061*	*.017*	*.303*	*.155*	*.457*	*.234*

NOTE: Eta squared effect size: =.01 and < .06: Small effect, >= .06: Medium effect, .14 or higher: Large effect

Table 4 shows country means for natural mortality (M) fishing mortality (F) and the exploitation ratio (E) as well as mean shell height. The Gambia sites have a lower mean natural mortality and a greater mean shell height than Ghana sites, suggesting that The Gambia physico-chemical parameters not only result in larger oysters but lower natural mortality. Hence, the physico-chemical parameters in Ghana suggest an environment less conducive for oyster growth and survival. The Gambia has a higher mean fishing mortality than Ghana. It suggests that the better environmental conditions for oysters in The Gambia may allow for higher fishing morality with little impact on exploitation ratio. While the previous statement can be considered speculative given the small sample size involved (only 6 sites, 3 per country), this should be considered a working hypothesis that deserves further study.

Table 4: Mean natural mortality, fishing mortality, exploitation ratio and shell height per country.

Country	Mean shell height (N=4200)	Mean Natural Mortality (N=3)	Mean Fishing Mortality (N=3)	Mean Exploitation Ratio (N=3)
Ghana	5.84	1.783	0.840	0.277
The Gambia	6.26	1.370	1.063	0.307

The Gambia sites have more mangrove habitat dominated oyster fisheries where oysters live on mangrove roots. In Ghana, oysters live on bottom substrate. Based on the differences in physico-chemical conditions, natural mortality of oysters, and location of oyster habitat, the estuarine and lagoon oyster ecosystems between the two countries are quite different.

Table 5 shows the same physico-chemical parameters and shellfish height for oysters as Table 3, but in this case, aggregated by fisheries health rank (over, fully, or under-exploited). There seem to be no apparent directional trends for the physico-chemical parameters consistent with the exploitation rank. Comparing site means of the physico-chemical parameters with fisheries health rank shows no statistically significant directional correlation (Spearman rho: $p > 0.10$, $n=6$, for all parameters). Dichotomizing the fisheries health rank into two groups - underexploited versus over and fully exploited - overexploited sites have lower mean salinity and mean depth as well as higher turbidity. However, while there seems to be differences qualitatively, analyzing using spearman correlation showed no significant relationships ($p < 0.10$, $n=6$), for all parameters.

Underexploited sites have greater shell height, higher salinity and greater depth compared to the over and fully exploited sites.

Table 5: Fisheries health rank by mean shell height and means of physico-chemical parameters

Fisheries Health Rank	Shell height (cm)	Temperature (0C)	DO (ug/l)	Salinity (ppt)	pH	Depth (m)	Turbidity (NTU)
Mean values of site physico-chemical parameters by Fisheries Health Rank							
0 (overexploited)	5.51	28.81	5.30	24.77	7.74	1.84	17.65
1 (fully exploited)	6.12	28.80	5.62	24.50	7.85	1.20	21.85
2 (underexploited)	6.49	28.11	5.22	34.20	7.46	2.97	5.91
Mean values of site physico-chemical parameters by Fisheries Health Rank dichotomized							
0 (over or fully exploited)	5.82	28.80	5.50	24.61	7.80	1.45	20.20
1 (under-exploited)	6.49	28.11	5.22	34.20	7.46	2.97	5.91

Table 6 shows mean values for natural mortality and shell height. Based on the fisheries health rank categories of over, fully, and underexploited sites. There seems to be no apparent pattern concerning natural mortality. Dichotomizing the data however does show underexploited sites with lower natural mortality rates than fully and over exploited sites, but it is not a statistically significant difference. As the underexploited sites have higher salinity and greater depth, it suggests these parameters may be influencing lower natural mortality rates.

Qualitatively, underexploited sites have lower natural mortality rates as well as higher salinity and greater depth than fully and over exploited sites.

Table 6: Fisheries health rank versus mean natural morality and mean shell height.

Fisheries Health Rank	Mean shell height (N=4201)	Mean Natural Mortality (N=3)
0 (overexploited) (N=2)	5.51	1.71
1 (fully exploited) (N=2)	6.12	1.73
2 (underexploited) (N=2)	6.49	1.30
0 (over or fully exploited) (N=4)	5.82	1.71
1 (under-exploited) (N=2)	6.49	1.30

Shellfish Consumption and Fishery Health

Our theory of change posited that improved shellfishery health would increase shellfish consumption. We compared the shellfisheries health ranks ('over', 'fully', and 'underexploited') to shellfish consumption data collected by the University of Ghana (as part of the nutrition component) and per capita food expenditures collected by ICRAF as part of the landscape food system and livelihoods component. Using linear regression analysis and controlling for sites via clustering and country as a factor, we found no statistically significant differences. This suggests we reject our hypothesis that improved shellfishery health would increase shellfish consumption, accepting the null hypothesis that there is no relationship between these variables.

> There were no statistically significant differences between any of the fishery health indicators and shellfish consumption or per capita food expenditures.

Income/Poverty and Fishery Health

Our theory of change posited that in sites with healthier shellfisheries, women shellfishers would have higher shellfishing income and overall household income as well as lower poverty rates. To assess this hypothesis, we looked at several variables from the UCC socio-economic survey of shellfishers. This included, household income (ranked ordinal variable), shellfish livelihood dependency (ranked percent of household income from shellfishing), and shellfishing income rank calculated from the household income and percent of household income from shellfishing variables (see Appendix 2 for specifics). We calculated a poverty/wealth index by applying questions associated with the poverty probability index (https://www.povertyindex.org/) including household size, consumption of eggs and corned beef, ownership of a TV, fan, or refrigerator, and whether the household cook fuel was gas, electric, or other fuel. A higher score indicates a wealthier household and a lower score a poorer household. This poverty index was used as another measure of household wealth or poverty as income data can be difficult for individuals to recall or estimate given variability in income daily, weekly, and seasonally for most fishing households.

We calculated a livelihood diversity score based on the number of household alternative income sources other than shellfishing. The hypothesis here is that greater livelihood diversity is related to higher household income. We treated all these variables as ranked ordinal data for statistical analysis purposes.

Table 7 shows the site means for the livelihood, poverty, and income variables by fisheries health rank. Only household income rank and livelihood diversity suggest a directional trend in relation to fisheries health. Income tends to be higher and livelihood diversity lower in healthier sites.

Table 7: Site means for income livelihood and poverty measures versus fisheries health rank

Fisheries Health Rank	N	Household Income Rank	Livelihood Dependency	Livelihood Diversity	Shellfish Income Rank	Poverty Index
overexploited	2	2.41	1.896	1.325	6.918	2.779
fully exploited	2	2.62	1.342	1.220	6.393	2.095
underexploited	2	2.94	1.667	1.000	8.389	3.528

We used Spearman correlation to compare fisheries health ranks (over, fully, and underexploited) with income and livelihood and poverty variables. Only livelihood diversity had a statistically significant ($p < 0.10$, one tailed test) negative correlation with the fisheries health rank (Table 8). These results do not support our hypothesis that healthier shellfisheries result in higher household income or lower poverty.

Higher livelihood diversity scores were associated with lower fisheries health rank. This finding does not support our hypothesis of livelihood diversity increases household income. However, this suggests that if shellfishers diversify livelihoods where fisheries health is lower, this may help to maintain household income, but not increase household income.

Table 8: Statistics for income, livelihood dependency, and poverty index versus fisheries health rank.

Variable	N	Spearman rho	Sig. (1-tailed)
Household income rank	6	.239	.324
Shellfish livelihood dependency	6	-.239	.324
Livelihood diversity	***6***	***-.717***	***.054***
Shellfish income rank	6	-.120	.411
Poverty/ wealth index	6	.359	.243

We reanalyzed the data using the dichotomous fisheries health rank variable (over and fully exploited versus underexploited) and using the Spearman correlation. Table 9 shows site level means per health rank and statistical results.

Household income, shellfish livelihood dependency, and shellfish income are all higher in the underexploited sites. The poverty/wealth index shows higher poverty (lower score) in the over and fully exploited sites, and livelihood diversity is lower in underexploited sites. This tends to support our hypotheses concerning fisheries health and income and poverty. However, only livelihood diversity and the poverty index are statistically significant ($p > 0.10$, 1-

Household income, shellfish livelihood dependency, and shellfish income are all higher in the underexploited sites. The poverty/wealth index shows higher poverty in the over and fully exploited sites, and livelihood diversity is lower in underexploited sites. However, only livelihood diversity and the poverty index showed statistical significance.

tailed test) and only moderately correlated. For the dichotomous analysis, the underexploited sites are the Tanbi and Densu – both are in urban/peri-urban areas. This may have accounted for the lower poverty and lower livelihood diversity differences as urban areas tend to have less poverty than rural areas and where households may rely on fewer livelihoods for sustaining their household. Therefore, the result between underexploited versus over and fully exploited sites could also be due to an urban-rural dynamic rather than the exploitation level. Future research could help tease out reasons for these differences and extent to which the urban-rural site dynamic is a factor in poverty and livelihood diversity differences.

Table 9: Statistics for income, livelihood dependency and poverty index versus fisheries health rank dichotomized.

Variable	Mean value for over and fully exploited (n=4)	Mean value for underexploited (n=2)	Spearman rho statistic	Sig. (1-tailed)
Household income rank	2.516	2.944	.207	.347
Shellfish livelihood dependency	1.619	1.667	.000	.500
Livelihood diversity	*1.272*	*1.000*	*-.621*	*.094*
Shellfish income rank	6.655	8.389	.000	.500
Poverty/wealth index	*2.437*	*3.527*	*.621*	*.094*

We tested livelihood diversity against household income, the poverty/wealth index, shellfishing livelihood dependency, and shellfishing income rank using the Spearman correlation of site means (n=6). There were no significant relationships (significance level of $p<0.10$, 1-tailed) between these variables and livelihood diversity. These results do not support our hypotheses that livelihood diversification affects income or poverty.

There was no significant relationship between household income, livelihood dependence, shellfishing income, or the poverty/wealth index and livelihood diversity.

It is important to note from this finding that since livelihood diversification does not increase overall household income, if increasing household income of shellfishers is an objective, livelihood diversification may not be a useful strategy to achieve it. Similarly, if increased economic resilience by decreasing dependence on shellfishing is an objective, livelihood diversification also does not seem to be appropriate.

3.3. Hypothesis 2: Management of Mangrove Management, Shellfish Yields and Stocks

Hypothesis 2: Shellfisher mangrove management actions improve mangrove habitat which in turn improves the health of shellfish stocks and yields.

Figure 14 below shows the causal path model for hypothesis 2.

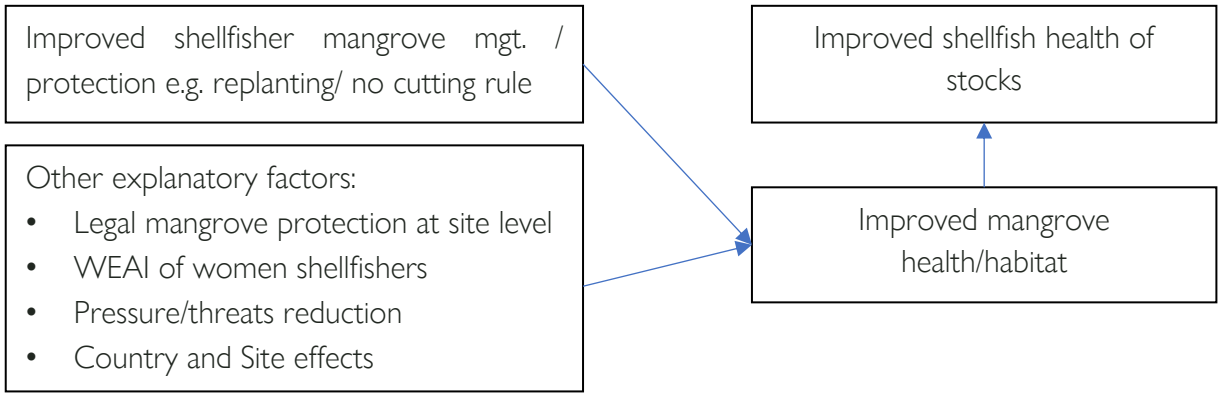


Figure 14: Causal path model for hypothesis 2.

The causal paths of IF – THEN statements represented by the arrows in the figure above are:

- IF improved gender sensitive governance, THEN improved mangrove habitat
- IF improved mangrove habitat, THEN improved shellfish health

Below are the simple model equations for predictor and outcome variables:

- Improved mangrove habitat = Improved gender sensitive governance + country + site
- Improved shellfish health/yields = Improved mangrove habitat + country + site
- (Gender sensitive governance = Legal protection + co-mgt + tenure + trad mgt + shellfisher mangrove mgt/protection)

Shellfisher Mangrove Management and Mangrove Health

A primary component of our theory of change model is that if women shellfishers actively protect mangroves, then mangrove habitat and health will improve. Measures of mangrove health were based on data collected by ICRAF at the six sites as well as a qualitative score of mangrove health by UCC (Table 10). ICRAF assessed the percent increase or decrease of mangrove area at each site between 2010 and 2020. An ordinal mangrove trajectory of change ranking was also determined based on the percent rate of change in mangrove cover in hectares between 2000-2010, and between 2010 and 2020, as assessed by the ICRAF mangrove cover change study. If the percentage of mangrove loss declined between the two time periods, we ranked it as an improvement. If the percent increase in

mangrove cover increased between the two time periods, that we considered it as an improvement. Conversely, an increased rate of change in mangrove lost or a decrease in rate of mangrove gained, we considered a decline in the trajectory of change. We then ranked sites as having a significant (3), modest (2), slight improvement (1) or a slight decline (0) in the rate of change. We assigned a qualitative, ordinal score to mangroves at each site based on UCC expert opinion of direct observations. We scored sites as having high (2), medium (1), or low (0) mangrove health.

Shellfisher protection of mangroves was based on review of secondary information (management plans with rules for mangrove protection, or lack thereof) and based on focus group discussions. Only the Densu and Tanbi sites had active mangrove protection rules by shellfishers.

All these data are at the site level, so we conducted only sites level statistical analysis. Reviewing the data in Table 10 below qualitatively, there seems to be no relationship between shellfisher protections for mangroves and mangrove health for any of the mangrove health measures used. While this is a small sample size, it does not support our hypothesis that shellfisher protections improve overall mangrove health in these sites. While shellfisher protections of mangroves are helpful, they may not be sufficient to see an overall site level change. Other factors may play a larger role in determining mangrove health.

There seems to be no relationship between shellfisher protections for mangroves and mangrove health for any of the measures used.

The percentage scale of mangrove change was mapped spatially to the entire site and not just to operational areas by the women shellfishery groups. A more granular assessment would be useful of women shellfisher mangrove sites where they have the greatest influence or networks on restoration and protection. Other measures such as level of effective enforcement by authorities and compliance or lack thereof by various mangrove users could have a more significant role in the health status of mangroves overall. The current study was limited in terms of these suggested additional factors.

Furthermore, women shellfishers may not always exercise mangrove or land tenure rights, and control or administration on resource use is unclear in some contexts. Sites without formal protection arrangements such as the case of Whin and Bulock also seem to have limited social and local institutional plans to improve local mangrove resources.

Table 10: Mangrove shellfisher governance and mangrove health scores per site.

Country	Site	Shellfisher Mangrove Protection	Mangrove Change 2010 - 2020 (percent)	Mangrove Trajectory of Change between 2000-2010 & 2010-2020	Mangrove Trajectory Ordinal Score	Mangrove Qualitative Health	Mangrove Health Ordinal score
Ghana	Densu	1	+313	significant improvement	3	low	0
Ghana	Narkwa	0	+680	significant improvement	3	moderate	1
Ghana	Whin	0	+37	modest improvement	2	high	2
The Gambia	Tanbi	1	-0.67	slight decline	0	moderate	1
The Gambia	Bulock	0	-1.36	slight improvement	1	high	2
The Gambia	Allahein	0	+10.4	modest improvement	2	low	0

Legal Mangrove Protection and Mangrove Health

Our theory of change model asserts that if there are legal protections of mangroves at the site level, then mangrove health will improve. In the six survey sites in our sample, both the Densu and Tanbi sites are RAMSAR designated sites and have plans that provide site specific protections of mangroves (scored as Yes=1 and No=0 in Table 11 below) in addition to general protections for all mangroves nationally in both countries. There seems to be no relationship between site level legal protections for mangroves and mangrove health for any of the mangrove health measures used.

While legal protections and site plans protecting mangroves are helpful enabling conditions, if not effectively implemented, they may not lead to site level changes, and other factors may play a larger role in determining mangrove health among these sites.

> There seems to be no relationship between legal site protections for mangroves and mangrove health for any of the measures used.

While this is a small sample size, it does not support our hypothesis that legal protection for mangroves improves overall mangrove health in these sites. In many other forestry contexts, it is not the presence of forestry laws that count but rather the enforcement and compliance levels that bring about change. Weak enforcement or compliance with rules can register unchanged or increased levels of degradation.

In the case of the current analysis, percent mangrove change may represent larger areas of habitat not related to administrative area boundaries where specific legislation may apply and therefore assembled data may have failed to show any correlations. We recommend further assessment to examine law enforcement and compliance levels by women shellfisher networks and other mangrove stakeholders as well as use of more locally refined mangrove health indicators covering more locations within sites.

Table 11: Mangrove legal governance and mangrove health scores per site.

Country	Site	Mangrove Legal Protection	Mangrove Change 2010 - 2020 (percent)	Mangrove Trajectory of Change between 2000-2010 & 2010-2020	Mangrove Trajectory Ordinal Score	Mangrove Qualitative Health	Mangrove Health Ordinal score
Ghana	Densu	1	+313	significant improvement	3	low	0
Ghana	Narkwa	0	+680	significant improvement	3	moderate	1
Ghana	Whin	0	+37	modest improvement	2	high	2
The Gambia	Tanbi	1	-0.67	slight decline	0	moderate	1
The Gambia	Bulock	0	-1.36	slight improvement	1	high	2
The Gambia	Allahein	0	+10.4	modest improvement	2	low	0

Women's Empowerment and Mangrove Health

Our theory of change also assumes if women are empowered then mangrove health will improve. We developed a simple women's empowerment score based on the five domains in the Women's

Empowerment in Agriculture Index (WEAI) (https://www.ifpri.org/project/weai) and adapted for a shellfisher context. We compared the women's empowerment scores from a UCC shellfisher survey to the ICRAF mangrove health variables. Table 12 shows the mean women's empowerment score per site.

Table 12: Mean women's empowerment score by site.

Women's Empowerment Score			
Site	Mean	N	Std. Deviation
Densu	10.80	15	1.935
Narkwa	5.35	20	1.461
Whin	6.00	8	.756
Tanbi	12.44	9	1.333
Bulock	8.70	27	2.367
Allahein	8.67	24	2.615

There were no statistical relationships ($p<0.10$ 1-tailed) using the Spearman rho correlation test between the mean women's empowerment score per site with any of the mangrove health rank scores or using linear regression with clustering for sites and controlling for country as a factor. Therefore, we must reject the hypothesis that increased women's empowerment (of shellfishers) increases mangrove health. It seems likely that other factors may be driving the mangrove health differences.

> There were no positive relationships between increasing women's empowerment scores and increased mangrove health on any of the mangrove health parameters used.

The mean women's empowerment score was positively correlated with both legal mangrove protection and shellfisher mangrove protection scores (Spearman rho = .828, p = 0.021; 1-tailed, n=6). The two sites with legal and shellfisher mangrove protection are the Densu and Tanbi sites. These sites had higher women's empowerment scores than the other sites and both sites have had significant interventions with women shellfishers and shellfish management including empowering women through use rights, co-management, financial skills development, and leadership development.

Pressure and Threats Reduction and Mangrove Health

Our theory of change model also asserts that in addition to improved governance and women's empowerment, pressure and threats reduction on the mangroves will improve health of mangrove systems. We created a pressure and threats score based on ICRAF assessments (Duguma et al., 2022) at each site. Table 13 shows the list of 17 pressure and threats categories and ranking. Scoring of pressure/threats were; high=2, medium=1, low or N/A=0. We used no weighting in scoring. A simple sum of scores on all 17 categories create a total pressure/threats score.

Table 13: Pressure and threats ranking and scores.

Identified pressures/threats	Relevance of the identified pressures					
	Densu	Narkwa	Whin	Tanbi	Bulock	Allahein
Population related pressure sand threats on mangroves in Ghana and The Gambia						
1. Wood for domestic energy	High 2	Medium 1	Medium 1	High 2	High 2	High 2
2. Wood for construction	Medium 1	Medium 1	Medium 1	High 2	High 2	High 2
3. Land clearing for farming	High 2	Medium 1	Medium 1	High 2	High 2	High 2
4. Land clearing for residential spaces	High 2	Medium 1	Medium 1	High 2	Medium 1	Medium 1
5. Household wastes	Medium 1	Low0	Low 0	High 2	Medium 1	Medium 1
6. Communal wastes	High 2	Medium 1	Medium 1	High 2	Medium 1	Medium1
7. Settlement based community infrastructures	High 2	Medium 1	Medium 1	High 2	Medium1	High 2
Total Pop pressure score	12	6	6	14	10	11
Economic activity related pressures and threats on mangroves in Ghana and The Gambia						
8. Extraction and sales of fuelwood and construction wood	High 2	Medium 1	Medium 1	High 2	Medium 1	High 2
9. Agricultural expansion	High 2	High 2	Medium 1	High 2	Medium 1	High 2
10. Tourism and recreation/cultural activities	Medium 1	Low 0	Low 0	Medium 1	Medium 1	High 2
11. Oyster collection by cutting roots of mangroves	High 2	Low 0	Low 0	High 2	High 2	High 2
12. Oyster steaming wood	Medium 1	Medium 1	Medium 1	High 2	High 2	High 2
13. Wood carvings, fences, houses, and boat construction	Low 0	Low 0	Low 0	High 2	Medium 1	High 2
14. Cutting mangroves for fish smoking	High 2	High 2	High 2	High 2	High 2	High 2
15. Extraction for medicinal purposes	Low 0	Low 0	Low 0	Low 0	Low 0	Low 0
16. Traditional aquaculture using mangrove woods to mimic the mangrove environment	High 2	Medium 1	Low 0	Medium 1	Low 0	Low 0
17. Salt mining and creation of spaces and piping pathways	High 2	Medium 1	Low 0	N/A 0	N/A 0	N/A 0
Total Econ pressure score	14	8	5	14	10	14
Total Pop+ Econ pressure score	12+14=26	6+8=14	6+5=11	14+14=28	10+10=20	11+14=25

SOURCE: ICRAF Technical Report 1, Women Shellfishers and Food Security Project, 2022.

Table 14 shows the data for the six sites. The total pressure score was not statistically correlated with any of the mangrove health measures using the Spearman rho test ($p < 0.10$; 1-tailed) even though the correlations were in the expected direction (negatively correlated). The total pressure score was moderately and negatively correlated with the mangrove health score (Figure 15). Total pressure scores were lower where mangrove health scores were higher. This provides only weak support of our hypothesis that pressure and threats reduction on mangroves will improve health of the mangrove systems.

> Total pressure scores were lower where mangrove health scores were higher, but not statistically correlated.

It is also interesting to note that sites with legal protections and shellfisher mangrove protections have the highest threat scores. This could be due to both these sites, Densu and Tanbi, being located adjacent to large urban cities which could be another confounding factor in this analysis.

Table 14: Total pressure and threat scores, mangrove health scores and governance protection scores per site.

Country	Site	Total Pressure and Threat Score	Mangrove Areal Change 2010 - 2020 (percent)	Mangrove Trajectory of Change between 2000-2010 & 2010-2020	Mangrove Trajectory Ordinal Score	Mangrove Qualitative Health	Mangrove Health Ordinal Score	Shellfisher Mangrove Protection	Mangrove Legal Protection
Ghana	Densu	26	313	significant improvement	3	low	0	1	1
Ghana	Narkwa	14	680	significant improvement	3	moderate	1	0	0
Ghana	Whin	11	37	modest improvement	2	high	2	0	0
The Gambia	Tanbi	28	-0.67	slight decline	0	moderate	1	1	1
The Gambia	Bulock	20	-1.36	slight improvement	1	high	2	0	0
The Gambia	Allahein	25	10.4	modest improvement	2	low	0	0	0

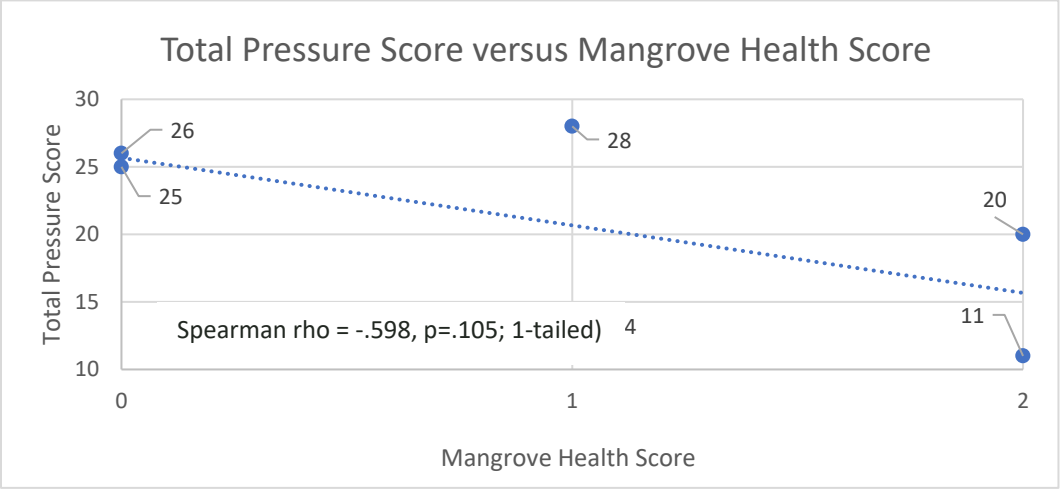


Figure 15: Relationship between site level total pressure score versus mangrove health score.

Shellfishery Health and Mangrove Health

The West African mangrove oyster lives attached to mangrove roots, and mangroves are essential habitat for the species. Therefore, our theory of change posits that improved mangrove habitat or health should improve shellfishery health.

Direct observations of oyster growing areas in Ghana and The Gambia have shown one significant difference between the countries. In Ghana, the shellfishing areas are on sandy and hard oyster reef bottom substrate, not necessarily on mangrove prop roots. It is the opposite case in The Gambia where the oysters are attached to the prop roots of mangroves, and unlikely to grow on the muddier

bottom substrates in The Gambia. In this case, the relationship between mangrove health and shellfish health may only apply to sites in The Gambia and may not hold true for Ghana. In order to assess these hypotheses, we examined mangrove health parameters from the ICRAF data in association with the UCC shellfish health parameters (mean shell height, exploitation ratio, fishing mortality, shellfisheries health rank).

Table 15 shows the data comparing mean shell height and mangrove parameters. There was no statistical relationship between any of the mangrove parameters with mean shell height.

Table 15: Mangrove health parameters and shellfish height.

Country	Site	Mean Shell Height	Mangrove Percent Change	Mangrove Change Trajectory	Mangrove Trajectory Score	Mangrove Health	Mangrove Health Score
Ghana	Densu	6.83	313	significant improvement	3	low	0
Ghana	Narkwa	4.60	680	significant improvement	3	moderate	1
Ghana	Whin	6.10	37	modest improvement	2	high	2
The Gambia	Tanbi	6.16	-0.67	slight decline	0	moderate	1
The Gambia	Bulock	6.49	-1.36	slight improvement	1	high	2
The Gambia	Allahein	6.13	10.4	modest improvement	2	low	0

Table 16 shows the other fisheries indicators versus the mangrove indicators. Using the Spearman rho correlation test there was no significant correlation between the mangrove percent change and mangrove change trajectory variables with any of the fisheries health variables.

Table 16: Mangrove health parameters and fisheries health parameters.

Country	Site	Natural Mortality	Fishing Mortality	Exploitation Ratio	Fisheries Health	Fisheries Health Rank	Mangrove Percent Change	Mangrove Change Trajectory	Mangrove Trajectory Score	Mangrove Health	Mangrove Health Score
Ghana	Densu	1.78	0.07	0.04	underexploited	2	313	significant improvement	3	low	0
Ghana	Narkwa	1.62	1.65	0.5	overexploited	0	680	significant improvement	3	moderate	1
Ghana	Whin	1.95	0.8	0.29	fully exploited	1	37	modest improvement	2	high	2
The Gambia	Tanbi	0.81	0.04	0.05	underexploited	2	-0.67	slight decline	0	moderate	1
The Gambia	Bulock	1.8	2.56	0.59	overexploited	0	-1.36	slight improvement	1	high	2
The Gambia	Allahein	1.5	0.59	0.28	fully exploited	1	10.4	modest improvement	2	low	0

Table 17 shows there were moderate correlations between the mangrove health rank and natural mortality, fishing mortality, and the exploitation ratio, and fisheries health rank. However, only the exploitation ratio was statistically correlated ($p < 0.10$, 1-tailed), but where exploitation ratio is higher where mangrove health is higher, opposite expactations.

Table 17: Spearman correlations between mangrove health rank and fisheries health variables.

Statistics	Natural Mortality	Fishing mortality	Exploitation ratio	Fisheries health rank
Spearman Correlation Coefficient	.598	.598	.717	.500
Sig. (1-tailed)	.105	.105	.054	.156
N	6	6	6	6

Under the assumption that only The Gambia sites will show a relationship between mangrove health and fisheries health variables, as the oysters live on the mangrove roots unlike in Ghana where they live on bottom substrate, the Gambia sites were analyzed separately. They showed no statistically significant correlations between the mangrove health variables and the fisheries health variables. Hence, there is no evidence to support the hypothesis that improved mangrove health leads to improved shellfisheries health.

There is no evidence to support the hypothesis that improved mangrove health leads to improved shellfisheries health.

Summary of Findings for Hypothesis 2

- There seems to be no relationship between shellfisher protections for mangroves and mangrove health for any of the measures used.
- There were no positive relationships between increasing women's empowerment scores and increased mangrove health on any of the mangrove health parameters used.
- Total pressure scores were lower where mangrove health scores were higher, but not statistically correlated.
- There is no evidence to support the hypothesis that improved mangrove health leads to improved shellfisheries health.

3.4. Hypothesis 3: Shellfish Consumption, Anemia, and Nutrition

Hypothesis 3: High consumption of shellfish and increased income from shellfishing contributes to lower prevalence of anemia in women of reproductive age and improves other nutrition variables. Shellfish consumption is shown as a main contributor to reduced anemia compared to other factors such as geographic factors or household and individual characteristics.

Figure 13 shows the causal path model for hypothesis 3.

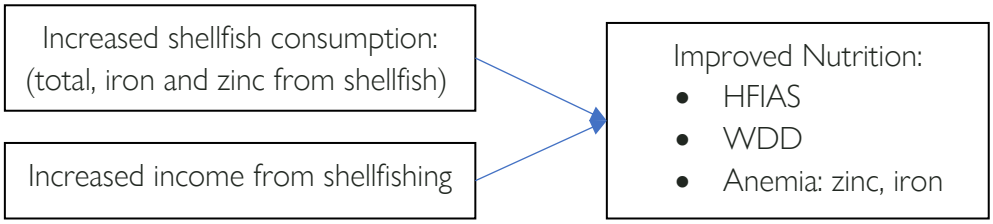


Figure 16: Casual path model for hypothesis 3.

The causal paths of IF – THEN statements represented by the arrows in the figure above are:

- IF increased shellfish consumption, THEN improved nutrition
- IF increased income from shellfishing THEN improved nutrition

Below are the simple model equations for predictor and outcome variables:

- Improved nutrition = increased shellfish consumption + country + site +
- Improved nutrition = increased income from shellfishing + country + site

Increased shellfish consumption and improved nutrition

Table 18 shows the mean site level oyster consumption variables and nutrition variables. The table also shows median oyster consumption grouped at the site level as the consumption data is highly skewed with most respondents reporting no consumption in either of the two 24 hr. recall periods, and a few high daily consumption totals. We removed one high value (401.6 g) extreme outlier from the oyster consumption cases for the analysis. Linear regression (or logistic regression for: any anemia, food secure, MDD-W achieved) with site clustering and country as a controlling factor, showed no statistically significant ($p < 0.10$) relationships between oyster consumption and any of the nutrition variables.

Table 18: Oyster consumption and nutrition variables grouped by site.

Site	Mean oyster consumption (g)	Grouped median oyster consumption (g)	Mean Hb (g/dL)	Mean anemia (percent)	Mean MDD-W	MDD-W achieved (percent)	Mean HFIAS	Mean food secure (percent)
Densu	9.593	.816	12.67	25	3.71	20	11.70	.06
Narkwa	6.699	1.438	12.89	19	3.83	23	12.79	.06
Whin	.262	.263	13.41	15	3.56	20	10.72	.12
Tanbi	2.165	.757	12.37	38	4.86	56	6.27	.13
Bulock	2.010	1.023	12.07	46	5.07	63	6.13	.16
Allahein	.966	.966	12.17	43	5.11	71	3.97	.34

These findings suggest that there is no relationship between oyster consumption and nutrition of shellfishers. Our hypothesis that increased oyster consumption improves nutrition is not supported.

> There is no relationship between oyster consumption and nutrition of shellfishers.

Increased income from shellfishing and improved nutrition

Table 19 below shows the mean values per site (or percent) for the income, wealth-poverty, per capita food expenditure, and nutrition variables.

Table 19: Mean site values for income, wealth-poverty, per capita food expenditure, and nutrition variables.

Site	Mean shellfish income dependence rank	Mean household income rank	Mean shellfish income rank	Mean per capita food expenditure	Mean wealth – poverty score
Income, wealth-poverty and expenditure variables					
Densu	1.11	2.00	4.00	13.30	4.63
Narkwa	2.15	1.85	5.80	12.34	4.08
Whin	1.48	2.33	5.62	8.61	4.46
Tanbi	2.22	3.89	12.78	15.76	5.29
Bulock	1.64	2.96	8.04	5.76	4.83
Allahein	1.44	2.94	7.63	6.66	5.06

Site	Mean Hb	Mean anemia	Mean MDD-W	MDD-W achieved (percent)	Mean HFIAS	Mean food secure (percent)
Nutrition variables						
Densu	12.67	0.25	3.71	0.20	11.70	.06
Narkwa	12.89	0.19	3.83	0.23	12.79	.06
Whin	13.41	0.15	3.56	0.20	10.72	.12
Tanbi	12.37	0.38	4.86	0.56	6.27	.13
Bulock	12.07	0.46	5.07	0.63	6.13	.16
Allahein	12.17	0.43	5.11	0.71	3.97	.34

Table 20 shows the statistical analysis between the income, wealth-poverty, per capita food expenditure, and nutrition variables. In most instances, we used only site level analysis using Spearman correlation. For the Hb and wealth-poverty measure, we used linear regression with site clustering and country as a controlling factor, For anemia, minimum dietary diversity achieved and food secure variables, which are binary outcome variables, logistic regression was used.

Table 20: Statistical analysis between income, wealth-poverty, expenditure, and nutrition variables.

Outcome	Predictor	Linear or logistic regression		Spearman correlation	
		beta coefficient or odds ratio* (CI 95 percent)	p-value	rho	p-value (1-tailed)
Hb	HH income rank			***-0.657***	***0.078***
Hb	shellfish income dependence rank			***-0.657***	***0.078***
Hb	per capita food expenditure			0.429	0.198
Hb	Wealth-poverty score	0.007 (-.066, .081)	0.797	***-0.714***	***0.055***
Anemia	HH income rank			***0.657***	***0.078***
Anemia	shellfish income dependence rank			-0.029	0.476
Anemia	per capita food expenditure			0.429	0.198
Anemia	Wealth-poverty score	0.007* (-.007, .022)	0.182	***0.714***	***0.055***
Dietary diversity score	HH income rank			0.543	0.133
Dietary diversity score	shellfish income dependence rank			0.143	0.394
Dietary diversity score	per capita food expenditure			-0.429	0.198
Dietary diversity score	Wealth-poverty score	***.067 (.001, .134)***	***0.01***	***0.657***	***0.078***
Minimum dietary diversity achieved	HH income rank			0.543	0.133
Minimum dietary diversity achieved	shellfish income dependence rank			0.143	0.394
Minimum dietary diversity achieved	per capita food expenditure			-0.429	0.198
Minimum dietary diversity achieved	Wealth-poverty score	***.917* (.826, 1.019)***	***0.036***	***0.657***	***0.078***
HFIAS	HH income rank			***-0.771***	***0.036***
HFIAS	shellfish income dependence rank			0.086	0.436
HFIAS	per capita food expenditure			0.543	0.113
HFIAS	Wealth-poverty score	***-.718 (-.926, .510)***	***0.001***	***-0.771***	***0.036***
Food secure	HH income rank			***0.754***	***0.042***
Food secure	shellfish income dependence rank			-0.290	0.478
Food secure	per capita food expenditure			-0.580	0.114
Food secure	Wealth-poverty score	***.777* (.713, .849)***	***0.001***	***0.725***	***0.052***

Significance at the P < 0.10 level in bold italics.

* denotes odds ratio for logistic regression, all others are beta coefficients for logistic regressions.

The wealth poverty score was significantly correlated with all the nutrition variables either at the $p < 0.10$ or $p < 0.05$ level. Household income rank was also significantly correlated with all the variables except the dietary diversity variables. Per capita food expenditure and shellfish income dependence rank were not statistically correlated with any of the nutrition variables. Hb and anemia prevalence had significant correlations with income and wealth predictor variables that were opposite our expected direction. Hb was higher where household income was lower, shellfish income dependency lower, and where the wealth-poverty score was lower. Anemia was higher where household income, shellfish income dependency, and the wealth-poverty score were higher. We have no explanation for this finding which is counter to our hypothesis. However, logistic regression at the case level shows that Hb and anemia were not related to the wealth-poverty measure. Either way, the findings do not support the hypothesis that increased income reduces anemia or increased Hb levels in the blood.

Per capita food expenditure and shellfish income dependence rank were not related to any of the nutrition variables.

Hb and anemia prevalence had significant correlations with income and wealth predictor variables that were opposite our expected direction.

However, all the other significant correlations were in the expected direction. Dietary diversity score and dietary diversity adequate was positively correlated with the wealth-poverty score. The HFIAS score (a higher score means higher food insecurity) was negatively correlated with the household income rank and the wealth-poverty score. A food secure household was positively correlated with household income rank and the wealth-poverty score. These findings do support the hypothesis that increased household income increases dietary diversity and food security. However, we must consider this with the caveat that dependence on shellfishing for income and per capita food expenditures are not statistically related to any of these nutrition variables.

Dietary diversity score and dietary diversity adequate were positively correlated with the wealth-poverty score. The HFIAS score (a higher score means higher food insecurity) was negatively correlated with the household income rank and the wealth-poverty score. A food secure household was positively correlated with household income rank and the wealth-poverty score.

Summary of Findings for Hypothesis 3

- Per capita food expenditure and shellfish income dependence were not related to any of the nutrition variables.
- Hb and anemia prevalence had significant correlations with income and wealth predictor variables that were opposite our expected direction.
- Dietary diversity score and dietary diversity adequate were positively correlated with the wealth-poverty score.

- The HFIAS score (a higher score means higher food insecurity) was negatively correlated with the household income rank and the wealth-poverty score.
- A food secure household was positively correlated with household income rank and the wealth-poverty score.

3.5. Hypothesis 4: Enriched Landscapes, Mangrove Management, Shellfisher Income, and Food Security

Hypothesis 4: Enriching landscapes around mangrove-shellfish estuaries systems with complementary food and nutrition sources reduces the extractive pressure on the mangroves thereby improving mangrove health and improves shellfisher household income and household food security.

Figure 17 below shows the causal path model for hypothesis 4.

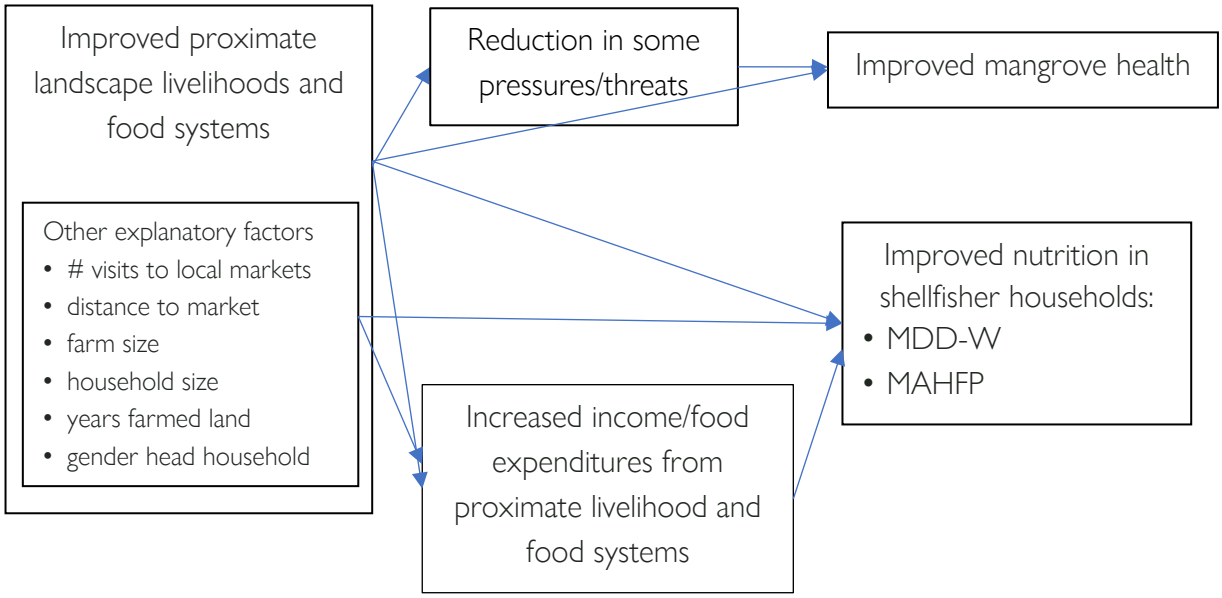


Figure 17: Causal path model for hypothesis 4.

The causal paths of IF – THEN statements represented by the arrows in the figure above are:

- IF Improved proximate landscape livelihoods and food systems THEN reduction in pressure/threats.

- IF Improved proximate landscape livelihoods and food systems THEN improved mangrove habitat.
- IF Improved proximate landscape livelihoods and food systems THEN improved nutrition.
- IF Improved proximate landscape livelihoods and food systems THEN Increased income/food expenditures from livelihood and food systems.
- IF reduction in pressure/threats THEN Improved mangrove habitat/ biodiversity.
- IF Increased income from livelihood and food systems THEN Improved nutrition.

Shown below are the simple model equations for predictor and outcome variables:

- Improved nutrition = improved livelihoods and food systems + other explanatory factors + country + site.
- Improved nutrition = increased income (food expenditure) from livelihoods/food systems + country + site.
- Increased income (food expenditure) from livelihoods = Improved proximate landscape livelihoods and food systems + other explanatory factors + country + site.
- Improved mangrove habitat/biodiversity = Reduced pressures + country + site.

Improved proximate landscape livelihoods

A primary component of our theory of change model for hypothesis 4 is that if proximate landscape livelihoods are improved then this will positively influence a reduction in threats, improve mangrove health, improve nutrition of shellfishing households, and increase income and increase food expenditures from proximate livelihood and food systems.

We use two measures of proximate landscape livelihoods as the predictor or independent variable. First, is a household food system score based on the number of responses to five questions in an ICRAF survey concerning growing vegetables, fruits, or other crops, keeping of livestock, and if the household collects food from the forest. The second is the livelihood diversity score from the UCC household survey on the number of sources of livelihoods in the household other than shellfishing ranging from zero to three.

The outcome or dependent variables (see hypothesis 2 and the appendix for scoring) include:

- A pressure and threats score based on ICRAF expert opinion.
- Several measures of mangrove health based on ICRAF site studies.
- Improved nutrition in shellfishing households – a minimum adequacy of household food provisioning (MAHFP) representing the number of months in a year the household has an adequate food supply (based on an ICRAF household survey), the dietary diversity score for women of reproductive age (MDD-W score ranging from 0 – 12 answers on whether they consumed in the last 24 hrs. something from one of 12 food groups), and whether that dietary diversity is considered adequate (MDDW Adequate = MDD-W > 5).

- Household income rank based on the UCC household survey and per capita food expenditures based on the ICRAF household survey. We used the median value rather than mean of household per capita food expenditure due to highly skewed data for this variable.

Table 21 shows the mangrove and food system variables per site.

Table 21: Mangrove and food system variables by site.

Site	Mangrove trajectory	Mangrove health score	Mean household diverse food system score	Mean Livelihood Diversity score	Total pressure/ threats score	Mean minimum adequacy of household food provisioning	Mean MDD-W Score	MDDW achieved (prevalence - percent of households)	Median per capita expenditure (US$/week)	Mean household income rank
Densu	significant improvement	low	0.7	1.1	26	9.5	3.7	20.0	9.0	2.0
Narkwa	significant improvement	moderate	1.5	1.2	14	10.2	3.8	23.5	9.8	1.9
Whin	modest improvement	high	2.1	1.0	11	11.0	3.6	19.7	6.8	2.3
Tanbi	slight decline	moderate	2.2	0.9	28	10.1	4.9	56.0	1.0	3.9
Bulock	slight improvement	high	3.5	1.5	20	10.6	5.1	62.9	4.4	3.0
Allahein	modest improvement	low	3.1	1.4	25	8.7	5.1	71.4	5.5	2.9

Table 22 presents the results of the analysis of the landscape livelihood predictor variables relationship to the above-mentioned outcome indicators. Mean household livelihood diversity score was not correlated with any of the outcome variables. The table shows that mean household diverse food system score was strongly correlated ($p<0.10$; 2-tailed, $n=6$) with many of the outcome variables (in bold italics in the table).

Two of these were opposite our expectations. The mean household diverse food system score was higher where mangroves show the least improvement or decline, and where median per capita food expenditure was lower. This suggests that when mangroves are declining, and in all likelihood, provide less food provisioning services, households may rely more on diverse food systems as a coping mechanism. In addition, households that rely on diverse household food systems may need to spend less on food as they may be growing more for home consumption and improving household income savings to meet other needs. In these cases, diverse household food systems anchored in a healthy mangrove resource base may provide a useful household resilience strategy.

The mean household diverse food system score was higher where mangroves show the least improvement or decline, and where median per capita food expenditure was lower which were opposite expectations.

Table 22: Results of statistical analysis of hypothesis 4 outcome and predictor variables.

Variables			Site level spearman correlation statistics	
Outcome group	Outcome	Predictor	rho	p-value
Pressure/threats				
	Pressure threat score	HH diverse food system	0.03	0.957
	Pressure threat score	Livelihood diversity	-0.26	0.623
Mangrove habitat				
	Mangrove trajectory	***HH diverse food system***	***-0.77***	***0.076***
	Mangrove trajectory	Livelihood diversity	0.15	0.781
	Mangrove health score	HH diverse food system	0.36	0.485
	Mangrove health score	Livelihood diversity	0	0.999
Nutrition				
	MAHFP	HH diverse food system	0.09	0.872
	MAHFP	Livelihood diversity	-0.09	0.872
	Diet diversity score	***HH diverse food system***	***0.77***	***0.072***
	Diet diversity score	Livelihood diversity	0.6	0.208
	Adequate diet diversity	***HH diverse food system***	***0.77***	***0.072***
	Adequate diet diversity	Livelihood diversity	0.6	0.208
Income				
	Per capita food expenditure	***HH diverse food system***	***-0.77***	***0.072***
	Per capita food expenditure	Livelihood diversity	0.09	0.872
	HH income	***HH diverse food system***	***0.77***	***0.072***
	HH income	Livelihood diversity	-0.09	0.872

Results that supported our hypotheses show that sites with higher mean diverse food system scores have higher mean MDD-W scores and higher prevalence of households with adequate diverse diets. Sites with higher mean diverse food system scores also have higher mean income ranks and lower per capita food expenditures.

Sites with higher mean diverse food system scores have higher mean MDD-W scores, higher prevalence of households with adequate diets, higher mean income ranks and lower per capita food expenditures.

The mean minimum adequacy of household food provisioning (MAHFP score) showed no relationship to livelihood diversity, the food systems score, per capita food expenditures, or household income (Table 22). These findings are counter to our hypotheses as none of our predictor variables seem to influence MAHFP. If improving adequacy of the household food provisioning year-round is an objective, then strategies to achieve this need to be re-examined.

These results provide limited support for our hypothesis that more diverse household food systems have nutritional and income benefits, and may also be a useful resilience strategy. However more diverse household food systems have no relationship to reducing pressure and threats on mangroves or improving mangrove health. MAHFP may not be a good outcome measure, or ways to improve it may be more elusive than previously thought.

Other explanatory factors

The hypothesis 4 model posits that other explanatory variables may also influence improved nutrition of shellfishing households, as well as increased income or food expenditures from proximate livelihood and food systems. These other variables include the following:

- Number of household visits to local markets in a week.
- Household distance to market.
- Household farm size.
- Number of adults in the household.
- Years the interviewee has farmed.
- Gender of the head of household.

We made no a-priori directions concerning these predictor variables relationship to the response variables. These variables use the mean values of households in each site based on the household responses to an ICRAF survey of shellfishing households.

Table 23 shows the mean values per site for other explanatory factors. Gender of household head is percent female.

Table 23: Mean values of other explanatory values and percent female headed households per site.

Site	Percent female head of household	Years farmed land	Distance to local market	Number of adults in household	Number visits to local markets	Farm size
Densu	55.7	.51	15.35	3.10	1.00	.09
Narkwa	39.1	3.22	6.45	3.74	4.45	.65
Whin	61.2	12.81	3.48	4.37	3.82	2.39
Tanbi	22.2	15.72	2.65	8.67	4.78	1.94
Bulock	7.1	14.36	1.46	8.36	6.50	4.04
Allahein	21.1	21.37	2.29	8.37	6.47	2.66

Other explanatory factors related to improved nutrition in shellfishing households

Table 24 shows spearman correlations of the other explanatory factors with the three nutrition indicators. There was no statistically significant relationship between MAHFP with any of the other explanatory factors. For the mean MDD-W score and MDD-W adequate nutrition variables, several other explanatory variables were significant at the $p < 0.1$ and $p < 0.05$ level. As we proposed no a-priori direction of the relationship in the initial hypothesis, we used 2-tailed tests for the other explanatory variables. Mean MDD-W and MDD-W adequate (percent of respondents) was higher where the mean years farmed was higher and where the number of visits to a local market weekly was higher. Mean MDD-W and MDD-W adequate was lower where the mean distance to a local market was greater and where the percent of female headed households was higher. Number of adults in the household and farm size showed no significant relationship with any of the nutrition variables. These findings provide support for our hypothesis, that two out of the three other explanatory factors influence nutrition.

> Mean MDD-W and MDD-W adequate was higher where the mean years framed was higher and where the number of visits to a local market weekly was higher, and lower where the mean distance to a local market was and percent of female headed households was greater.

Table 24: Spearman correlations between other explanatory factors and nutrition indicators.

Nutrition variable	Statistics	Percent female head of household	Years farmed land	Distance to local market	Number of adults in household	Number visits to local markets	Farm size
Mean MAHFP	Correlation Coefficient	-.086	-.257	-.086	-.143	-.029	.257
	Sig. (2-tailed)	.872	.623	.872	.787	.957	.623
	N	6	6	6	6	6	6
Mean MDD-W score	Correlation Coefficient	-.771	.771	-.771	.657	.886*	.600
	Sig. (2-tailed)	***.072***	***.072***	***.072***	.156	***.019***	.208
	N	6	6	6	6	6	6
MDD-W adequate (percent)	Correlation Coefficient	-.771	.771	-.771	.657	.886*	.600
	Sig. (2-tailed)	***.072***	***.072***	***.072***	.156	***.019***	.208
	N	6	6	6	6	6	6

* - Correlation is significant at the 0.05 level (2-tailed).

Other explanatory factors related to increased income/food expenditures from proximate livelihood and food systems

Table 25 shows Spearman correlations between the other explanatory factors, median per capita food expenditures, and mean income rank. Four out of six of the other explanatory variables are statistically correlated ($p < 0.10$, $p < 0.05$) with median per capita food expenditures and mean household income rank. Median per capita expenditures are higher in sites with a higher percent of

female headed households and where the mean distance to local markets is greater. Median per capita expenditures are lower in sites with lower mean years farmed and lower number of adults in the household. Households with lower mean household income have a higher percentage of female headed households and greater mean distance to market. Mean household income is higher in sites with higher mean years farmed and mean number of adults in the household.

Table 25: Spearman correlations between other explanatory factors, mean income rank, and median per capita food expenditures.

Nutrition variable	Statistics	Percent female head of household	No. of Years farmed	Distance to local market	Number of adults in household	Number visits to local markets	Farm size
Median per capita food expenditures	Correlation Coefficient	.771	-.771	.771	-.886*	-.657	-.600
	Sig. (2-tailed)	.072	.072	.072	.019	.156	.208
	N	6	6	6	6	6	6
Mean Household income rank	Correlation Coefficient	-.771	.771	-.771	.886*	.657	.600
	Sig. (2-tailed)	.072	.072	.072	.019	.156	.208
	N	6	6	6	6	6	6

* - Correlation is significant at the 0.05 level (2-tailed).

The results suggest that households that are more experienced at farming and have more adults rely less on buying food and depend more on what they grow. While not statistically significant, results also suggest those with larger farm sizes also spend less on food. The results also suggest higher household income in male headed households, households with more adults (more potential income earners), where households are closer to local markets, households with more years of experience farming, and, while not statistically significant, larger farm size. These results parallel earlier findings that households with more diverse food systems spend less on food but have higher household income. Note that median per capita food expenditures and mean household income were not correlated with any of the nutrition variables (see Table 26 below).

> Households that are more experienced at farming and have more adults rely less on buying food and likely depend more on what they grow.
>
> Higher household income is found in male headed households, households with more adults, where households are closer to local markets, and with more years of farming experience.

The findings partially support our hypothesis that several (but not all tested) other explanatory factors influence income and food expenditures, not just diversified food systems.

Reduction in pressures/threats and improved mangrove health

We assessed this hypothesis in the hypothesis 2 section. The results showed weak evidence that this hypothesis is true.

There is some weak evidence to support the hypothesis that reduced pressure and threats improves mangrove health.

Increased income/food expenditures from proximate livelihood and food systems, and improved nutrition in shellfishing households

The theory of change posits that increased shellfisher income or per capita food expenditure in shellfishing households will improve nutrition in shellfishing households (MAHFP score, MDD-W score, and MDD-W adequate). We used mean household income rank per site here based on the UCC survey data. Mean per capita food expenditures is based on ICRAF survey data; total household food expenditures divided by the number of adults in the household. Nutritional variables were described previously for MDD-W, MDD-W adequate and MAHFP.

There is no evidence to support the hypothesis that that increased household income or per capita food expenditure in shellfishing households will improve nutrition in shellfishing households.

Table 26 below shows the results of spearman rank correlation tests. None of the predictor variables were statistically related to the outcome variables. These results do not support our hypothesis that increased shellfisher income or per capita food expenditure in shellfishing households will improve nutrition in shellfishing households.

Table 26: Correlation statistics for nutrition variables with income, expenditure variables.

Variables			Site level spearman correlation statistic	
Outcome group	Outcome	Predictor	rho	p-value
Nutrition	MAHFP	Per capita food expenditure	0.03	0.957
	MAHFP	HH income	-0.03	0.957
	MAHFP	Shellfisher income rank	-.029	0.957
	Diet diversity score	Per capita food expenditure	-0.54	0.266
	Diet diversity score	HH income	0.54	0.266
	Diet diversity score	Shellfisher income rank	.714	.111
	Adequate diet diversity	Per capita food expenditure	-0.54	0.266
	Adequate diet diversity	HH income	0.54	0.266
	Adequate diet diversity	Shellfisher income rank	.714	.111

Summary of Findings and Conclusions for Hypothesis 4

- The mean household diverse food system score was higher where mangroves show the least improvement or decline, and where median per capita food expenditure was lower, which were opposite expectations.
- Sites with higher mean diverse food system scores have higher mean MDD-W scores, higher prevalence of households with adequate diets, higher mean income ranks, and lower per capita food expenditures.
- Mean MDD-W and MDD-W adequate was higher where the mean years farmed was higher and where the number of visits to a local market weekly was higher, and lower where the mean distance to a local market and percent of female headed households were greater.
- Results suggest that households that are more experienced at farming and have more adults rely less on buying food and depend more on what they grow. In addition, results suggest higher household income in male headed households, households with more adults, where households are closer to local markets, and in households with more years of farming experience.
- There is weak evidence to support the hypothesis that reduced pressure and threats improves mangrove health.
- There is no evidence to support the hypothesis that that increased shellfisher income or per capita food expenditure in shellfishing households will improve dietary diversity or minimum adequate household food provisioning even though there is evidence elsewhere that higher income improves dietary diversity.

4. CONCLUSIONS

Hypothesis 1

Table 27 provides a summary of our hypotheses that we confirmed, and those we did not confirm, based on this analysis for hypothesis 1. There was evidence in this study that co-management and women's empowerment does lead to improved shellfish stocks. There was little evidence that heathier shellfisheries results in higher shellfish consumption among women shellfishers, improved income, or lower poverty. Analyzed data showed no evidence that improved livelihood diversity improves household income. While we did not expect the later conclusions, it is possible that the cross sectional rather than times series research design, data collection methods, indicators used, and the small number of sites sampled in this study may have led to these negative findings. Field observations also revealed many women shellfishers substitute off-season shellfishery activities with petty trading activities to diversify livelihoods but probably does not generate enough wealth or improve savings significantly to allow increased household consumption. Results suggesting increased shellfisheries health does not improve incomes significantly are curious and perhaps a pointer to poor development of the shellfisheries value chains. We recommend that those hypotheses not confirmed, regarding income and poverty, be further examined by researchers in subsequent studies. Other exogenous or local factors may also play a more important role.

Table 27: Summary of hypotheses and conclusions for hypothesis 1.

Hypothesis	Conclusion	Comments
Improved governance will improve the health of the shellfish resource.		A statistically significant trend of higher governance scores were observed with higher fisheries health rank and mean shell height. Lower fishing mortality and exploitation ratios had a higher governance score.
Women's empowerment will improve the health of the shellfishery.		Sites with a higher fisheries health rank and higher mean shell height had higher women's empowerment scores. Sites with higher fishing mortality and exploitation ratios had lower women's empowerment scores. These relationships showed statistical significance using either linear regression or spearman rho.
Physico-chemical parameters of the waterbody influences shellfishery health.		Qualitatively, underexploited sites have greater shell height, higher salinity and greater depth compared to the over and fully exploited sites. The Gambia sites have a lower mean natural mortality and greater mean shell height than Ghana sites, suggesting Ghana waterbodies environmental conditions may be less conducive for oyster growth

Hypothesis	Conclusion	Comments
		and survival. However, trends were not statistically significant when comparing site level means.
Improved shellfishery health increases shellfish consumption.		No evidence to support this. However, we had no data on shellfish yields per harvester so while shellfisheries health was used as an indicator, yields per harvester may be a better approach to this question in the future.
In sites with healthier shellfisheries, women shellfishers have higher shellfishing income, overall household income, and lower poverty rates.		Little evidence to support this. Only when underexploited sites were compared to over and fully exploited sites was there a statsitically significant relationship with the poverty indicator.
Greater livelihood diversity is related to higher household income.		There was no significant relationship between household income, livelihood dependence, shellfishing income, or the poverty/wealth index and livelihood diversity.

Hypothesis 2

Table 28 provides a summary of our hypotheses that we confirmed, and those we did not confirm, based on this analysis for hypothesis 2. There was no evidence in this study that shellfisher protections or legal site protections (RAMSAR sites in our cases) improve mangrove health. This suggests potential weak or non-existent implementation of RAMSAR plans and that shellfishers efforts at protection are not sufficient to see change in mangroves at the site level. Qualitatively, there was weak evidence that where pressures and threats were lower, mangrove health was higher. This aspect of the theory of change deserves further investigation, with detailed analysis and weighting for measuring severity of threats. The USAID guidelines for rating direct threats may provide a useful approach (USAID, 2017). We found no relationship between mangrove health and shellfish health even though the exiting scientific literature suggests a relationship between mangroves and fish yields. Again, the measures used in our study can be improved, factoring in overall mangrove area in relation to the number of shellfishers per unit of mangrove area and harvests per shellfisher, measures not used in this study. In addition, while mangroves may play a role, fishing effort, exploitation levels, and shellfish governance factors may be the overwhelmingly main drivers regardless of mangrove health. For example, Densu has few mangroves but a healthy and well-managed shellfishery. Tanbi has an abundance of mangroves and a healthy and well-managed shellfishery as well. Extent of mangrove habitat in an estuary may be more related to the overall potential total shellfish yields at the site. We did not test this relationship in our study but it has evidence in the scientific literature (Anneboina and Kumar, 2017).

Table 28: Summary of hypotheses and conclusions for hypothesis 2

Hypothesis	Conclusion	Comments
Shellfisher protection and or legal site protection of mangroves will strengthen mangrove health.		There seems to be no relationship between shellfisher protections or legal site protection for mangroves and mangrove health. Therefore, it is likely that other factors are influencing mangrove health.
Women's empowerment will improve mangrove health.		There were no positive relationships between higher women's empowerment scores and increased mangrove health for any parameters used in this study.
A reduction in total pressures/threats will improve mangrove health.		Weak evidence of a relationship where total pressure scores were lower where mangrove health scores were higher, but not statistically correlated.
Improved mangrove health improves shellfish health.		There is no evidence to support the hypothesis that improved mangrove health leads to improved shellfisheries health even when examining only The Gambia sites.

Hypothesis 3

Table 29 provides a summary of our hypotheses that we confirmed, and those we did not confirm, based on this analysis for hypothesis 3. There was no evidence in our study that increased shellfish consumption decreases anemia levels. The low consumption levels of oysters by women shellfishers being the main reason. While oysters are a good source of iron and zinc, consumption levels would have to increase by a large amount to have any real impact. However, Adu-Afarwuah et al. (2022) advised not to promote increased consumption due to substantial health risks from heavy metal contamination in oyster tissues in Ghana sites, most notably of mercury. Government agencies should identify local sources of contamination and work to reduce heavy metal loading into the estuaries. This study did suggest that increased household income and greater wealth improves food security and having adequate dietary diversity, but unrelated to shellfish income. However, Adu-Afarwuah et al. (2022), using a different approach (Poisson regression and assessing each country separately), showed opposite results not supporting this hypothesis. Given the conflicting evidence depending on approach used, this hypothesis is worthy of further study.

Table 29: Summary of hypotheses and conclusions for hypothesis 3.

Hypothesis	Conclusion	Comments
Increased shellfish consumption decreases anemia and increases Hb in the blood.		No evidence. Consumption levels are low.
Increased shellfish consumption improves nutrition.		No evidence. Consumption levels are low.
Increased shellfish income and household wealth improves nutrition.		Statistical evidence that household income and wealth improve food security and dietary diversity but no evidence they reduce anemia or increase Hb levels in the blood.

Hypothesis 4

Table 30 is a summary of our hypotheses that we confirmed, and those we did not confirm, based on this analysis for hypothesis 4. There was no evidence from our study that improving proximate landscape livelihoods reduces pressure and threats to mangroves or improves mangrove health. Our study suggests that increasing proximate landscape livelihoods increases household income but decreases per capita food expenditures, due to more reliance on locally grown food and reducing the need to purchase food. Household characteristics can also influence nutrition, household income, and food expenditures. There was no evidence that household income or per capita food expenditure in shellfishing households will improve MAHFP or dietary diversity in shellfishing households. This is confusing with findings in hypothesis 3 which showed household income and wealth influenced other nutrition measures - the HFIAS score and being food secure. While the wealth measure was related to dietary diversity, household income and shellfisher income was not, probably due to the seasonality of the shellfishery activities and substitution with even lower value petty trading activities. Hence, while there were mostly negative findings on dietary diversity measures (except when using the wealth-poverty score) in the hypothesis 4 analysis, there was supporting evidence for the food security measures in the hypothesis 3 analysis. Chegini et al. (2021) have shown that food security in rural areas of Iran has complex associations with income, household, welfare, and other household characteristics that are similar to our findings. Given the mixed results here and complexity of relationships, more in-depth research is needed with respect to shellfishing household income, wealth, and various nutrition measures with some factors having more influence than others.

Table 30: Summary of hypotheses and conclusions for hypothesis 4.

Hypothesis	Conclusion	Comments
Improvements in proximate landscape livelihoods reduce pressure and threats to mangroves.		No evidence to support this.
Improvements in proximate landscape livelihoods improve mangrove health.		Most of the mangrove indicators were not related to the proximate food systems score except a weak correlation with mangrove health rank.
Improvements in proximate landscape livelihoods improve nutrition of shellfishing households		Weak correlations with the dietary diversity variables but not with the minimum adequacy of household food provisioning score.
Improvements in proximate landscape livelihoods increases income and food expenditures from proximate livelihood and food systems.		Weak statistical evidence that improvements in proximate landscapes increase household income but reduce per capita food expenditures. The relationship between improved landscape livelihoods and food expenditure was opposite expectations but suggests as households grow more diverse food themselves, they seem to rely less on food purchases, most likely by consuming more of what they grow.
Other explanatory variables may improve nutrition of shellfishing households, as well as increased income or food expenditures from proximate livelihood and food systems.		Statistical evidence that several explanatory variables - years farmed, number of visits to a local markets weekly, distance to a local market, and female headed household seem related to dietary diversity measures.
Increased shellfisher income, household income or per capita food expenditure in shellfishing households will improve nutrition in shellfishing households.		No evidence to support this.

Limitations of the Study

While we rejected some hypotheses, it could be that our methodology and the ways we measured the parameters may have led to some of the negative results. In addition, the small sample size of sites in cases of qualitative analysis and for aspects of the quantitative analysis with clustering could have led to negative results and should be confirmed by subsequent studies. A larger sample of sites and use of 95 percent confidence levels ($p < 0.05$) as the standard for statistical significance is recommend for any follow-up studies as we used a less conservative confidence level of ($P < 0.10$) due to the small number of sites. Other studies should also consider different sampling methods or ways of measuring the variables used to assess our model in this study. Better information on shellfishing

income, market prices, harvest levels per shellfisher, or fishers per hectare of mangrove would be helpful. Longitudinal studies over multiple sites with control (no governance) and treatment (governance improved) sites should also be considered. Lastly, the sheer number of statistical tests conducted in this study could have resulted in false positive findings as well (and considering a liberal $p < 0.10$ significance level) and those positive findings should also be reconfirmed (or not) in subsequent studies. The focus on a sample of women shellfisher respondents rather than all households in shellfishing communities might have influenced the results.

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APPENDIX 1: Survey Instruments

Semi-structured interview questions for shellfishery key informants (UCC)

Name of Site_____

Country: _____

Key informant Sex: Male __ Female __

Type: __Women shellfisher
__Adult within a shellfishing household
__Local government official
__Other specify: _____

Please describe the shellfishery in your area.

1. What types/species are harvested: oysters, clams, and/or gastropod or other?
2. How many people harvest these shellfish in the estuary/site? Consider all communities surrounding the estuary. How many communities around the estuary are involved in harvesting?
3. Who harvests? Women and/or men and/or children? Would you consider them poor or well off?
4. Describe the livelihoods of the women and households involved in shellfishing. Do they only do this activity for a livelihood or do they have other livelihoods and sources of income? If other, what are they? Do they also fish in the estuary or nearby river or sea? If no, do other people in the community fish, and if so, using what gears and what types of species do they catch?
5. On average, how many can one person harvest in a day (kgs or other unit of measure such as a tin can, pail and approx. weight of unit of measure.)
6. In an average month, how many days can be spent harvesting? Describe if there are seasonal variations in amount harvested due to rain or other seasonal events that may limit harvest and how does catch rates vary by season?
7. Are there months when no harvesting takes place? If yes, which months and why?
8. Describe how the product is harvested and whether boats are used and tools used if any. How is the product processed? Boiled and shucked, kept while/fresh, shucked and dried or smoked or other process?
9. Describe proportion of the harvest that is kept for family consumption and proportion that is sold.
10. If sold, where are the markets, distance to the markets, and prices per unit (pail, tin, handful, etc.)? Explain if prices vary by season or depending on how the product is processed?

11. Is there any aquaculture or farming of shellfish in the estuary? Or do seedlings get transplanted from one area to another? Are shells utilized? For what purposes? Are they ever returned to the estuary or places where shellfish is harvested?

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

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

Describe how the shellfish are managed

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

Describe the uses and condition of mangroves in your area

1. To what extent are mangroves harvested in the estuary?
2. By whom? Men, women, community members or people outside the community? Used for household only or sold in or outside the community?
3. How much do they earn in a given day if sold?
4. Mangroves are used for what purposes? Such as fuel wood for cooking smoking fish, building construction, sold for cash in local towns, medicinal or dying preserving cloths or fishing nets? other?
5. Compared to 10 and 5 years ago, have the condition/health of the mangroves changed? Degraded, regenerated, or about the same. Extent they have been cut or replanted or naturally regenerated? Are the changes due to cutting or other causes – natural or filling for settlements or businesses? Explain.

6. Are there any rules or prohibitions of using mangroves? Explain? By whom – local, traditional, government?
7. Are mangroves protected by law (e.g. illegal to cut?)
8. How are they managed – local traditional by a government agency?
9. What needs to be done to maintain a healthy fishery and mangroves?
10. How can the livelihoods of shellfishers could be improved?

Individual and Household Socio-economic Questionnaire of Shellfishers Households (UCC)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

>>> Shellfishing dependency is higher with a higher score

5. Alternative livelihood options during lean/closed shellfishing seasons

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

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

Score 0 if no alternative sources, and score 1 if they have a primary, 2 if primary and secondary, 3 if primary, secondary and tertiary. Sum for a livelihood diversity score 0-3.

Women's empowerment score (adapted from the Women's Empowerment in Agriculture Index and USAID Women's Learning Initiative) *It measures the roles and extent of women's engagement in the agriculture sector in five domains:*

1. *decisions about agricultural production,*
2. *access to and decision-making power over productive resources,*
3. *control over use of income,*
4. *leadership in the community, and*
5. *time use.*

Adapted for shellfishing and limiting the questions to no more than 4 per domain:

1. Production: Decision making on shellfishing

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

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

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

3. Income: Control over use of income

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

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

4. Leadership: Group Membership

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

5. Time: Workload from shellfishing

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

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

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

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

Focus group discussion assessment of wild food, fodder & crop-based biodiversity (ICRAF)

Interviewer/facilitator name: _____ Date:____ /_____/_____/

Name of note taker: /_____/

Country: /_____/

Interviewee information

1. Name of district/_____/
2. Name of village/_____/
3. Total number of participants in Focus Group Discussions (FGD): /____/
4. Total number of male participants: /____/
   Number of male participants 15-24 years old: /____/
5. Total number of female participants /____/
   Number of female participants 15-24 years: /____/ (remember to fill and attach the participants list):
6. Kindly tell me all types of livelihood activities/enterprises you are involved in this place?
7. What type of grazing method is mostly used by farmers around here?
8. What are the most commonly produced/collected tree and/or forest products in this community?
9. Where are these products sourced from (e.g. trees planted and/or managed on farm, collected from community forest, collected from natural forest, or other to be specified)?
10. Raise your hands if you, yourself, have been involved in the PRODUCTION of tree/forest products, such fruits/nuts, fodder, honey. in the past year. *(record the numbers of hands raised)*

Source: Trees on farms (cultivated or managed)

Product	Yes/No	Estimate amount per HH
Fruits/nuts		
Honey		
Fodder		
Other e.g. mushrooms		

Source: Forests (wild sourced)

Product	Yes/No	Estimate amount per HH
Fruits/nuts		
Honey		
Fodder		
Other e.g. mushrooms		

11. Raise your hands if you, yourself, have been involved in the COLLECTION of products that depend on trees or forests, such as fruits/nuts, honey, bees wax, medicinal plants, bushmeat, fodder. in the past year. *(record the numbers of hands raised)*

Source: Trees on farms (cultivated or managed)

Product	Yes/No	Estimate amt per HH/yr.
Fruits/nuts		
Honey		
Fodder		
Other e.g. mushrooms		

Source: Forests (wild sourced)

Product	Yes/No	Estimate amount per HH/yr.
Fruits/nuts		
Honey		
Fodder		
Other e.g. mushrooms		

12. Raise your hands if you, yourself, have SOLD any of such tree products or tree-related products during the past year. *(record the numbers of hands raised)*

Source: Trees on farms (cultivated or managed)

Product	Yes/No	Estimate amount per HH
Fruits/nuts		
Honey		
Fodder		
Other e.g. mushrooms		

Source: Forests (wild sourced)

Product	Yes/No	Estimate amount per HH
Fruits/nuts		
Honey		
Fodder		
Other e.g. mushrooms		

13. Are community members interested in indigenous wild foods and fodder use? If yes, why? If not why?

14. In your opinion which wild food types have the potential to benefit community members?

List of wild food sources (names)	Reason	List of wild fodder sources/names	Reason

Why are these not being widely produced and traded?

15. Do you think farmers are willing to invest in production of indigenous wild food and fodder resources? If yes which ones? If not how could this situation be improved?

16. List all tree species in your village that provides food, fodder, medicinal and other product values

(The Facilitator should start by supporting the participants to list all relevant tree species and then the product specific questions that pertain to each. Add as many new rows as necessary; do not necessarily stop or reach 9. The Notetaker should record all the key points recorded in each column, and write this down in a block note as necessary)

Tree species (common name)	Tree species (Local name)	Product that can be sold or can help produce other products (fruits/ nuts, fodder, timber, fuelwood, honey, medicinal etc.)	Who would mostly produce, collect and/or add value[1], to each product? Men (=M), women (=W) or both (=B)?	Who would sell or market each product? Men (=M), women (=W), both (=B), or people from outside (=O)?	Potential importance of this product for women (or men)[2] in this community (1= being very important; 2= being important; 3=being less important)
1.					
2					
3					

[1] Adding value (value addition) is the process of changing or transforming a product from its original state into a more valuable state. Common examples include processing, sorting, grading, and packaging.

[2] Use women or men depending on whether it is a female or male FGD.

17. From the list you have provided, what are the 5 most important in terms of livelihood support (income, products) tree products or tree-related products for you as women (or men)[3] and briefly explain the reason for each selection. *(The Facilitator should stress the gender of the participants in this question.*

5 priority tree or tree related product	Brief reason for their selection
1.	
2.	
3.	

[3] Use women or men depending on whether it is a female or male FGD.

18. What are (or could be) some of the challenges in collecting, producing and marketing your five priority tree related products?

The Facilitator should support the participants to assess and agree on the potential challenges that could be encountered in developing producing, collecting/harvesting, adding value and marketing each priority product and rank these from 1 (most important) to 4 (least important). The Note-Taker is to document key challenges expressed under each column.

Priority tree or tree related product	Challenges in accessing inputs	Challenges in collection/harvesting	Challenges in marketing (selling or buying and selling to others)
1.			
Rank challenges from 1 to 4			
2.			
Rank challenges from 1 to 4			
3.			
Rank challenges from 1 to 4			
4.			
Rank challenges from 1 to 4			

19. List all agricultural crops in your village that provides food, fodder and other product values

(The Facilitator should start by supporting the participants to list all relevant food and feed crops and then the product specific questions that pertain to each. Add as many new rows as necessary. The Notetaker should record all the key points recorded in each column, and write this down in a block note as necessary)

Agricultural Crop (common name)	Local name	Produce/Product that can be sold	Who would produce: Men (=M), women (=W) or both (=B)?	Who would sell or market each product? Men (=M), women (=W), both (=B), or people from outside (=O)?	Potential importance of this product for women (or men)[4] in this community (1= being very important; 2= being important; 3=being less important)
1.					
2					
3					
4					
5					
6					

[4] Use women or men depending on whether it is a female or male FGD.

20. What are (or could be) some of the challenges in producing, and/or marketing of your five priority crops?

The Facilitator should support the participants to assess and agree on the potential challenges that could be encountered in producing and marketing each priority product and rank these from 1 (most important) to 4 (least important). The Note-Taker is to document key challenges expressed under each column.

21. How can the key challenges be addressed, both by yourselves or your wider community and/or through support from the outside? What groups are already involved in activities related to each prioritized tree product and what could be priority actions for future value chain development work? *(The Facilitator should place emphasis on the second column, i.e. supporting the participants to come up with ways they themselves can address the key challenges, focusing support needed from the outside as only something to address key gaps. The Note-Taker is to write key points agreed under each column.)*

Priority or tree related product	Ways you or your wider community could address the MAIN challenges (your copping strategy)	Support needed from the outside	Groups in community already collecting/ producing, adding value and/ tree or marketing priority product if any	Priority actions going forward
1.				
2.				
4.				

22. List main foods (cultivated and wild sourced) and their months of availability (harvest months)

Cultivated food types	Calendar month when available											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Fruit/food trees												
Vegetables												
Pulses												
Staples												
Wild food types (harvested from forests)												

23 List the fodder types, including crop residues available throughout the year:

List of fodder species/Names	Month fodder is available											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Types of crop residues used												
Types of other plant/tree parts used												

PARTICIPANT LIST: Focus Group Discussion

	Name	SEX (M /F)	Since when have you been in this village? (Year)	In which of the wild food & fodder are you involved?
1.				
2.				
3.				
4.				
5.				

Household questionnaire on food production and consumption (ICRAF)

[Interviewer: Please read this to the respondent verbatim.]

"Hello. My name is _____and we are from the [World Agroforestry Centre, (ICRAF)]. We are part of a team conducting a study on available diverse forest and tree food and feed uses to complement local nutrition needs for people and to support livestock production.

We would like to interview you for this study. The information and insights we collect from you are for research purposes only. We will use this information and insights to inform our research only. It will otherwise remain confidential, and your name will not be explicitly or implicitly identified in the analysis produced by our team. We anticipate no risks to your participation in this interview/discussion.

Participation in this interview/discussion is voluntary and you may refuse to participate, discontinue the interview/discussion at any time, or skip any question you do not want to answer.

Also, we would ask you to grant us permission to use your photograph for our publications, displays, and other lawful purposes."

SECTION A: PRE – INTERVIEW INFORMATION

County Name:	Sub-county:
Village Name:	Household ID:
Enumerator:	
Interview Date: Start Time: End Time:	GPS Co-ordinates Longitude: Latitude: Elevation:
Name of Respondent:	
Mobile Contacts of Respondent:	Year of birth:
	Relation of Respondent to HH head: 1=Self 2=Spouse 3=Other (Specify)

SECTION B: FAMILY/HOUSEHOLD (HH) PROFILE

1.	Name of HH head:		Mobile Number of HH head:
3.	Age of HH head:		
4.	No. of adults in your household (≥16yrs)		What is the size of this farm in acres?
6.	How many years have you farmed this land? …….		

SECTION C: HOUSEHOLD FOOD PRODUCTION

7.	Do you currently grow vegetables?	1= yes 2=no		
8.	If yes, which ones? (Please tick (√) in the boxes) and indicate whether they are mainly for own consumption (OC), Mainly for Sale (S), Both (B), Other (O)			
9.				Indicate whether OC, S, B, O
		Kales		
		Cabbage		
		African nightshade		
		Amaranth		
		Cow pea leaves		

		Crotalaria			
		Spider plant			
		Jute mallow			
		Ethiopian kale			
		Pumpkin leaves			
		Bean leaves			
		Others (specify)			
10.	Main use of vegetable products grown	1= mainly own consumption 2= mainly for sale 3= both (in approx. equal amounts) 99= other (specify)			
11.	Do you currently grow fruits?	1= yes 2= no			
12.	If yes, which ones? (Please tick (√) in the boxes) and indicate whether they are mainly for own consumption (OC), Mainly for Sale (S), Both (B), Other (O)				

13.	Exotic		Indicate whether OC, S, B, O	Indigenous		Indicate whether OC, S, B, O
	Mangoes			Baobab		
	Avocado (Parachichi)			Tamarind		
	Guava			Vitex spp		
	Oranges			Grewia		
	Lemon			Ziziphus spp.,		
	Pawpaw			Rhus spp.,		
	Pineapple			Carissa spp., Mukawa)		
	Gooseberry			Ximenia americana,		
	Pears			Borassus,		
	Tangerine (Sandara)			Doum palm,		
	Loquats			Syzygium		
	Java plum			Annona senegalensis		
	Jack fruit			Strychnos		
	Sweet banana (ndizi)			Capparis spp.		
	Banana			Ficus spp.(Kionywe)I		
	Watermelon					
	Plums					
	Apples					
	Passion fruits					
	Others (Specify)					

14.	Main use of fruits grown		1= mainly own consumption 2= mainly for sale 3= both (in approx. equal amounts) 99= other (specify)		
15.	Do you grow other crops such as staples, pulses and cash crops?		1 = Yes, 0= No	Of the other crops grown, please indicate whether they are mainly for own consumption (OC), Mainly for Sale (S), Both (B), Other (O)	
16.	If yes, which ones? (Please tick (√) in the boxes)			Tick box	Indicate whether OC, S, B, O (key provided above)
			Maize		
			Sorghum		
			Millet		
			Cassava		
			Cowpeas		
			Beans		
			Pigeon pea		
			Green grams		

			Lentils		
			Black eye peas		
			Coffee		
			Tea		
			Others		
17.	Main use of crops grown	1= mainly own consumption 2= mainly for sale 3= both (in approx. equal amounts) 99= other (specify)			
18.	Do you keep livestock?			1 = Yes 0= No	
19.	Type of Livestock and number of animals Cows / Goats/ Sheep/				
20.	How often did you visit the local market in the last week?	0 = Did not visit the market 1 = Once a week 2 = Twice a week 3 = Thrice a week 4 = Four times a week 5 = Five times a week 6 = Six times a week 7 = Daily 88 = don´t know	In general per week, how much money do you spend on buying food for your family/household? Amount:..... 88 = don´t know		
21.	What is the distance from your home to the local market you use (in Km)				
22.	How often per week do you buy foods from the following food groups and how much money do you spend per week on each food group?	**Food group**	**Ghanaian Cedi / Gambian Dalasi per week**		
		Starchy staple			
		Pulses, nuts			
		Vegetables			
		Fruits			
		Meat or fish			
		Milk			
		Eggs			
		Fats or oils			
		Sugar			

23.	Do you collect food from the forest? Yes /No	Type and rank	Months
24.	If yes, what types of food? (Rank order 1= most, 4 =least) Fruits Vegetables Nuts and Seeds Roots and Tubers What types of fodder are obtained from local forests?		

25.	What are the main months in the year when food is collected from the forest? January / February / March/ April/ May/ June/ July/ August/ September/ October/ November/ December 25.1 What are the main months in the year when fodder is obtained from forests?		

26. What is the origin for majority of the trees on your farm? (Mainly natural, mainly planted, same amount planted and natural)

27. Please list kind of trees species present on farm (record in common & scientific names)

28. Has the tree cover in your farm decreased or increased in the last 10 years?
    - If increased, what has led to this increase?:
    - If decreased, what has led to this decrease?:

29. Do you plan to plant more trees on your farm in the coming 12 months? If so which ones? If not please state reasons?

30. Have trees in the landscape (in your locality) increased, decreased or stayed about the same in the last 10 years?
- stayed the same (no change for this)
- If Increased, would you say it is as a result of; a) More tree planting by others b) better forest protection, c) tree planting projects, d) livestock control e) others (*specify*)
- If decreased, would you say it is because of; a) More people in the area b) clearing for other land-uses c) firewood d) charcoal e) fire f) livestock g) others (*specify)*

31. Do you have any problems with cultivating/growing trees that provide food? 0=No 1=Yes
    If yes, what type of problems?

32. Would you like to plant other types of trees on your farm? 1=yes 0=no
    If yes, which types of trees
    List species and Use: Timber, Firewood, Medicinal, Fertilizer, Other

    In your opinion what do you consider in decision to select a particular fruit species for investment?

    What factors pose challenges?

33. Have you received training related to tree farming? Yes No
    If Yes, What topics?

SECTION D: FARM INPUTS AND FOOD MARKETS

[This part of the questionnaire seeks to understand the social networks within the area]

Is there a nearby tree nursery or tree seedling purchase point, where you have purchased tree seedling(s) before? yes=1 no=0
If yes, please fill in the table below. [*List up to 3 nurseries or seedling purchase points*]

Name of nursery	Location and contact	Distance from homestead (minutes)	Tree species purchased	Did you buy in the last 6 months yes=1 no=0	Did you buy in the last 12 months yes=1 no=0	Were the seedlings OK? (quality of seedling and its growth performance) yes=1 no=0

What challenges do you encounter with local tree nurseries which you would like to see improved?

Lack of seedlings (quantities)
Lack of diversity of types of seedlings (for fruits, etc..)
Lack of varieties (for one species e.g. Mango)
Low quality of seedlings (they are tired looking/ dry/ sick- pests/disease)
Too expensive
Lack of knowledge by nursery staff (on species/ varieties/ management)
Lack of information provided by nursery staff (on species/ varieties/management)
Other

Where do you usually source your seed crops for planting?
Neighbor = 1 uy from agro-vets = 2 Seeds from previous harvest = 3 Others = 4 (please specify)_____

SECTION E: HOUSEHOLD DIETARY DIVERSITY

Please describe the foods (meals and snacks) that were consumed by all the household members yesterday during the day and night. Start with the first food eaten in the morning. *(Consider foods eaten by **any member of the household**, and **exclude** foods purchased **and** eaten outside of the home]. Write down all food and drinks mentioned by the respondent. When the respondent has finished, probe for meals and snacks not mentioned.* Number of adults (≥ 18 years) joining the meals yesterday: ____Number of children (< 18 years) joining the meals yesterday: ____

Breakfast	Snack	Lunch	Snack	Dinner	Snack

When the respondent recall is complete, fill in the food groups based on the information recorded above. For any food groups not mentioned, ask the respondent if a food item from this group was consumed.

	Food group	Examples	Response
1	CEREALS	maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g. bread, noodles, spaghetti, porridge or other grain products) + insert local foods e.g. ugali, porridge or pastes or other locally available grains	___ yes (1) ___ no (0)
2	VITAMIN A RICH VEGETABLES AND TUBERS	pumpkin, carrots, squash, or sweet potatoes that are orange inside + other locally available vitamin-A rich vegetables (e.g. red sweet pepper)	___ yes (1) ___ no (0)
3	WHITE TUBERS & ROOTS	white potatoes, white yams, white cassava, or other foods made from roots	___ yes (1) ___ no (0)
4	DARK GREEN LEAFY VEGETABLES	dark green/leafy vegetables, including wild ones + locally available vitamin-A rich leaves such as amaranth, cassava leaves, kale, spinach etc..	___ yes (1) ___ no (0)
5	OTHER VEGETABLES	other vegetables (e.g. tomato, onion, eggplant) , including wild vegetables	___ yes (1) ___ no (0)
6	VITAMIN A RICH FRUITS	ripe mangoes, cantaloupe, apricots (fresh or dried), ripe papaya, dried peaches + other locally available vitamin A-rich fruits	___ yes (1) ___ no (0)
7	OTHER FRUITS	other fruits, including wild fruits	___ yes (1) ___ no (0)
8	ORGAN MEAT (IRONRICH)	liver, kidney, heart or other organ meats or blood-based foods	___ yes (1) ___ no (0)
9	FLESH MEATS	beef, pork, lamb, goat, rabbit, wild game, chicken, duck, or other birds	___ yes (1) ___ no (0)
10	EGGS	chicken, duck, guinea hen or any other egg	___ yes (1) ___ no (0)
11	FISH	fresh or dried fish or shellfish	___ yes (1) ___ no (0)
12	LEGUMES, NUTS & SEEDS	beans, peas, lentils, nuts, seeds or foods made from these	___ yes (1) ___ no (0)
13	MILK AND MILK PRODUCTS	milk, cheese, yogurt or other milk products	___ yes (1) ___ no (0)
14	OILS & FATS	oil, fats or butter added to food or used for cooking	___ yes (1) ___ no (0)
15	SWEETS	sugar, honey, sweetened soda or sugary foods such as chocolates, candies, cookies and cakes	___ yes (1) ___ no (0)
16	SPICES, CONDIMENTS, BEVERAGES	spices(black pepper, salt), condiments (soy sauce, hot sauce), coffee, tea, alcoholic beverages OR local examples	___ yes (1) ___ no (0)
17	Sugarcane		___ yes (1) ___ no (0)

SECTION F: FOOD AVAILABILITY (Seasonality)
MONTHS OF ADEQUATE HOUSEHOLD FOOD PROVISIONING (MAHFP)

	QUESTIONS AND FILTERS	CODING CATEGORIES	SKIP
	We/I are interested to understand better if there are particular times during the year when food supply for the household is low or less than normal? When responding to these questions, please think back over the last 12 months. 1 = Yes, 0= No		
	In the past 12 months, were there any months in which you did not have enough food to meet your family's needs? Yes/No DO NOT READ THE LIST OF MONTHS. WORKING BACKWARD FROM THE CURRENT MONTH, PLACE A ONE IN THE BOX IF THE RESPONDENT IDENTIFIES THAT MONTH AS ONE IN WHICH THE HOUSEHOLD DID NOT HAVE ENOUGH FOOD TO MEET THEIR NEEDS.	☐	IF NO, END HERE
	If yes, which were the months (in the past 12 months) when there was not sufficient food available to meet the family's needs?		
A	March	A…….. ☐	
B	February	B…….. ☐	
C	January	C…….. ☐	
D	December	D…….. ☐	
E	November	E…….. ☐	
F	October	F…….. ☐	
G	September	G…….. ☐	
H	August	H…….. ☐	
I	July	I…….. ☐	
J	June	J…….. ☐	
K	May	K…….. ☐	
L	April	L…….. ☐	
	MAHFP Tabulation plan Twelve months minus the total number of months out of the previous 12 months that the household was unable to meet their food needs. Values for A through L will be either "0" or "1". (12) - Sum (A + B + C + D + E + F + G + H + I + J + K + L)		

30.	If "foods are not available": Which foods are most frequently not available and when? *More than one answer is possible. Please specify the type of foods. RECORD 1=yes, 2=no*			
	Food group	Y/N	Month(s) not available	
	Roots, tubers and plantain			
	Cereals			
	Pulses, nuts and seeds			
	Vegetables			
	Fruits			
	Animal sourced products			

Do you have any further question to us or a certain comment you want to make? *Thank you for your time and participation*

Women's health socio-demographic questionnaire (UG)

Name of this woman:_____	Participant ID ☐☐ Interviewer number ☐☐

I would first like to ask you some questions about yourself.

IN WHAT MONTH AND YEAR WERE YOU BORN?	Month ☐☐ Year ☐☐☐☐	Don't know, enter '99' or '9999'
HOW OLD ARE YOU? *PROBE:* HOW OLD WERE YOU AT YOUR LAST BIRTHDAY? *COMPARE MONTH AND YEAR OF BIRTH AND STATED AGE; CORRECT ONE IF NECESSARY*	Age ☐☐ (in completed years) (enter '99' if unknown)	
HAVE YOU EVER ATTENDED SCHOOL?	Yes 1 No 2 Don't know 9	->NEXT Q -> Q11 -> Q11
WHAT IS THE HIGHEST LEVEL OF SCHOOL YOU ATTENDED? HOW MANY YEARS AT THIS LEVEL DID YOU COMPLETE?	Circle # years DK Code completed Kindergarten 0 0 1 2 3 9 Primary 1 0 1 2 3 4 5 6 9 JSS-Junior Secondary 2 0 1 2 3 9 SSS-Senior Secondary 3 0 1 2 3 9 Vocational/ commercial/ nursing/ technical/ teaching 4 0 1 2 3 9 Tertiary/college/univ 5 0 1 2 3 4 5 6 9 Don't know 9	
NOW I WOULD LIKE YOU TO READ THIS SENTENCE TO ME. *SHOW SENTENCE ON THE CARD TO THE RESPONDENT.* *IF RESPONDENT CANNOT READ WHOLE SENTENCE, PROBE:* CAN YOU READ PART OF THE SENTENCE TO ME?	Cannot read at all 1 Able only to read only parts of sentence 2 Able to read whole sentence 3 No sentence in required language (specify)_____ 4 Blind, mute, visually/speech impaired 5	
What is your marital status now?	Never married, never lived with a man 1 Currently married 2 Living with a man, but not married 3 Divorced 4 Separated 5 Widowed 6	

As you know, some women take up jobs for which they are paid in cash or kind. Others sell things, have a small business or work on the family farm or in the family business. In the last seven days, have you done any of these things or any other work?	Yes 1 No 2	-> Next Q -> Q14
WHAT IS YOUR JOB OUTSIDE THE HOME?	No job 0 Unskilled labor 1 Skilled labor 2 Agriculture 3 Shop or office 4 Own business 5 Professional 6 Other (specify: _____) 88 Don't know 99	
In the last 24 hours, how many cigarettes did you smoke?	Number ☐☐	
ARE YOU PREGNANT NOW?	Yes 1 No 2 Unsure/ don't know 9	-> Next Q -> Q17 -> Q17
HOW MANY MONTHS PREGNANT ARE YOU?	Number of months ☐☐	
HOW MANY TIMES, IN TOTAL, HAVE YOU BEEN PREGNANT? *IF PREGNANT NOW, INCLUDE THIS PREGNANCY.* *IF NEVER PREGNANT, ENTER "00".* *IF RESPONDENT DOES NOT KNOW, CIRCLE "99".*	Number of times ……...…… ☐☐ Don't know 99	00->Q22
DURING YOUR LAST PREGNANCY, DID YOU TAKE IRON OR FOLIC ACID SUPPLEMENTS FOR 90 DAYS OR MORE?	Yes 1 No 2 Unsure/ don't know 9	
Following your last pregnancy (i.e. after delivery), did you take any vitamin A capsules? *Show vitamin A capsule.*	Yes 1 No 2 Not sure if it was vitamin A 9	
HOW MANY TIMES, IN TOTAL, HAVE YOU GIVEN BIRTH TO A BABY? *INCLUDE STILL BIRTHS AND LIVE BIRTHS*	Number of times ☐☐	00->Q22
Are you currently breastfeeding a child?	Yes 1 No 2	

POVERTY PROBABILITY INDEX

I would next like to ask you some questions about your household.

For Ghana, use the following set of questions:

HOW MANY MEMBERS ARE THERE IN YOUR HOUSEHOLD?	Number ☐☐	

In the past month, have you purchased any chicken eggs (fresh or single)?	Yes 1 No 2 Don't know 99	
In the past month, have you purchased any raw or corned beef?	Yes 1 No 2 Don't know 99	
What is the main construction material used for the outer wall of your house?	Mud/mud bricks/earth.. 1 Other 2 Don't know 99	
What is the main fuel used by the household for cooking?	Wood/crop residue/sawdust/animal waste.. 1 Other 2 Don't know 99	
Does any member of the household own a gas stove?	Yes 1 No 2 Don't know 99	
Does any member of the household own a refrigerator?	Yes 1 No 2 Don't know 99	
Does any member of the household own a fan?	Yes 1 No 2 Don't know 99	
Does any member of the household own a television?	Yes 1 No 2 Don't know 99	

For The Gambia, use the following set of questions:

In what region does this household reside?		
How many members does the household have?	6 or less 1 7 or more 2 Don't know 99	
How many children aged 0 to 6 are household members	None or 1 1 2 or more 2 Don't know 99	
Has the household head attended school?	Yes 1 No 2 Don't know 99	
What is the main material of the roof of your house?	Zinc 1 Straw 2 Concrete/cement 3 Tile/slate/other 4 Don't know 99	
Does your household have a fan?	Yes 1 No 2 Don't know 99	
Does your household have a table?	Yes 1 No 2 Don't know 99	

In the last 30 days, did the household purchase gas?	Yes 1 No 2 Don't know 99	
In the last 30 days, did the household purchase clothing?	Yes 1 No 2 Don't know 99	
In the last 12 months, has your household raised cattle (oxen, cows)?	Yes 1 No 2 Don't know 99	

ANEMIA MEASUREMENT

Now we would like to do a fingerpick to measure anemia.

Hemoglobin concentration	Hb (g/dL) ☐☐.☐	

ANTHROPOMETRIC MEASUREMENTS

Woman's weight	Kilograms (kg) ☐☐☐.☐	
Woman's height	Centimeters (cm) ☐☐☐.☐	
Reason why weight or height measurement missing	Disabled, cannot stand on scale 1 Disabled, cannot measure height 2 Uncooperative or uncontrollable 3 Other (specify) _____ 8 Refused 9	

Date of data collection	☐☐/☐☐/☐☐ Day Month Year
Final result of woman data collection	(enter code from below) ☐
FINAL RESULT CODES: Completed interview and accepted participation in blood collection 1 Completed interview and refused participation in blood collection 2	Refused interview and all data collection 3 Woman not home or not available 4 Other (specify) _____ 8

Comments about data collection with this woman:

24-hour dietary recall and Minimum Dietary Diversity-Women (MDD-W) (UG)

Participant ID: _____ Date: _____

Enumerator: Now I'd like to ask you to describe everything that you ate or drank yesterday during the day or night, whether you ate it at home or anywhere else. Please include all foods and drinks, any snacks or small meals, as well as any main meals. Remember to include all foods you may have eaten while preparing meals or preparing food for others. Please also include food you ate even if it was eaten elsewhere, away from your home.

1) Let's start with the first food or drink consumed yesterday. Did you have anything to eat or drink when you woke?
    a. If yes, what?
    b. Anything else?
2) Did you have anything to eat or drink later in the morning?
    a. If yes, what?
    b. Anything else?
3) Did you eat or drink anything at mid-day?
    a. If yes, what?
    b. Anything else?
4) Did you have anything to eat or drink during the afternoon?
    a. If yes, what?
    b. Anything else?
5) Did you have anything to eat in the evening?
    a. If yes, what?
    b. Anything else?
6) Did you have anything else to eat or drink in the evening before going to bed or during the night?
    a. If yes, what?
    b. Anything else?

Note: For each eating episode, after the respondent mentions foods and drinks, probe to ask if she ate or drank anything else. Continue probing until she says "no, nothing else." If the respondent mentions a mixed dish like a soup or stew, ask for all the ingredients in the mixed dish. For mixed dishes where it is possible to pick out ingredients or consume only broth, ask if she herself ate each ingredient or if she only had the broth. Continue to probe about ingredients until she says; "nothing else."

As the respondent recalls foods and drinks, mark the corresponding item in the "Description/ examples to be adapted" column and mark '1' in the response column for that row on the questionnaire. If more than one item in a row is mentioned, mark each item. If the same food or drink is mentioned more than once, you do not need to mark it again after the first time.

Required – Rows A–N (14 rows) will be aggregated during analysis into the ten MDD-W food groups			
	Food categories	**Description/examples to be adapted** Consult **Appendix 2** and replace the example foods below with items commonly consumed in the survey area(s).	**Consumed** Yes = 1 No= 0
A	**Foods made from grains**	*Porridge, bread, rice, pasta/noodles or other foods made from grains*	___yes (1) ___no (0)
B	**White roots and tubers and plantains**	*White potatoes, white yams, manioc/cassava/yucca, cocoyam, taro or any other foods made from white-fleshed roots or tubers, or plantains*	___yes (1) ___no (0)
C	**Pulses (beans, peas and lentils)**	*Mature beans or peas (fresh or dried seed), lentils or bean/pea products, including hummus, tofu and tempeh*	___yes (1) ___no (0)
D	**Nuts and seeds**	*Any tree nut, groundnut/peanut or certain seeds, or nut/seed "butters" or pastes*	___yes (1) ___no (0)
E	**Milk and milk products**	*Milk, cheese, yoghurt or other milk products but NOT including butter, ice cream, cream or sour cream*	___yes (1) ___no (0)
F	**Organ meat**	*Liver, kidney, heart or other organ meats or blood-based foods, including from wild game*	___yes (1) ___no (0)
G	**Meat and poultry**	*Beef, pork, lamb, goat, rabbit, wild game meat, chicken, duck or other bird*	___yes (1) ___no (0)
H	**Fish and seafood**	*Fresh or dried fish, shellfish or seafood*	___yes (1) ___no (0)
I	**Eggs**	*Eggs from poultry or any other bird*	___yes (1) ___no (0)
J	**Dark green leafy vegetables**	*List examples of any medium-to-dark green leafy vegetables, including wild/foraged leaves*	___yes (1) ___no (0)
K	**Vitamin A-rich vegetables, roots and tubers**	*Pumpkin, carrots, squash or sweet potatoes that are yellow or orange inside (see **Appendix 2** for other less-common vitamin A-rich vegetables)*	___yes (1) ___no (0)
L	**Vitamin A-rich fruits**	*Ripe mango, ripe papaya (see **Appendix 2** for other less-common vitamin A-rich fruits)*	___yes (1) ___no (0)
M	**Other vegetables**	*List examples of any other vegetables*	___yes (1) ___no (0)
N	**Other fruits**	*List examples of any other fruits*	___yes (1) ___no (0)

APPENDIX 2: Variables used in the analysis

Hypothesis 1

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
Shellfish Governance		independent
Co-management	Binomial presence or absence Y/N	independent
Tenure or Use rights	Binomial Y/N	independent
Traditional management	Binomial Y/N	independent
Women's empowerment score	Ordinal scale ranging from 0-15;based on questions in 5 WEAI domains (sum = Production score + Resources score+ Income score + Leadership score + Time score)	independent
Water Quality		independent
Salinity	PPT - parts per thousand - mean value per site over 12 months	independent
Temperature	^{O}C - mean value per site over 12 months	independent
Dissolved Oxygen (DO)	mg/l - mean value per site over 12 months	independent
pH	Unitless scale from 0-14; mean over 12 months	independent
Depth	mean in meters at sampling sites	independent
Turbidity	NTU - Nitrogen Turbidity Unit; mean value per site over 12 months	independent
Shellfish Health		dependent/indep
Shellfish height	Height of oyster shell in cm. (and mean) based on samples taken monthly at several stations per site	dependent/indep
Fishing mortality	Fm – calculated number for each site over an annual period	dependent/indep
Exploitation ratio	E – calculated number for each site over an annual period	
Shellfish health	Ordinal ranking: Overexploited: E = > 0.5, F> 1; Fully exploited: E => 2.5, <0.5, F =>.1 <1.0: Underexploited: E < 2.5, F <0.1; Rank: 0 – overexploited, 1 – fully exploited, 2- underexploited	dependent/indep

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
Shellfish health dichotomized	Shellfish health fully or overexploited = 0, underexploited = 1	dependent/indep
Shellfish Consumption		
Oyster consumption	Continuous: mg/day	dependent
Income		
Household income rank	ordinal scale in 6 income range bins	dependent
Livelihood dependency	Ordinal score based on income dependence on shellfishing: less than half, about half, more than half, all	dependent
Livelihood diversity	Number of sources of household income other than shellfishing	
Shellfish income rank	Ordinal score based on household income rank and livelihood dependency multipliers; range 0-24	
Poverty index	Based on PPI; sum of responses on 7 questions	
ICRAF household per capita food expenditure of adults (US$)	Number in USD household expenditures per week divided by number of adults in households	dependent

Variable name	Scoring/definition
Poverty score	Each answer coded Y=1, N = 0
HHsize_less_than_six	1. Are there less than 6 members (1-5 members) in your household?
Purchased_eggs	2. In the past month, have you purchased one or more chicken eggs?
Purchaed-corned_beef	3. In the past month, have you purchased any beef or corned beef?
Main_fuel_gas_elec	4. Is the main fuel used by the household for cooking gas or electric or something other than wood, crop residue, sawdust, or animal waste?
Own_fridge	5. Does any member of the household own a refrigerator?
Own_fan	6. Does any member of the household own a fan?
Own_TV	7. Does any member of the household own a television?
Poverty_score	Sum of 7 items above. Possible score ranges from 0-7. The higher the score the wealthier the household, the lower the score, the poorer the household.
Shellfish_income d	ordinal per household: bin of percent of total household income: less than half, half, more than half , all (0,1,2,3)
Shellfish_income_multiplier	assign multiplier based on bin of percent of total household income from shellfishing (shellfish income): less than half, half, more than half , all (.25,.5,.75,1)
Shellfish_income rank fraction	calcualte: household_income rank X shellfish_income_multiplier

Variable name	Scoring/definition	
Shellfish_income_rank_whole_number	convert shellfish_income_rank to whole number rank (e.g. .25 = 1, .5 = 2, .75 = 3, 1 = 4, 1.25 =5 etc. for possible range of 0-24	
WEAI		
Production_mgt		For decisions about how the shellfishery is managed (e.g. deciding on timing of a seasonal closure).
Production_mgt	2	I have input and women mainly make the decisions
Production_mgt	1	I and other women have some input into the decisions
Production_mgt	0	I and other women have no or little input, men make all the decisions
Production_decision		For decisions on when, how and where I collect shellfish?
Production_decision	0	I have no input in the decision
Production_decision	1	I have a little bit of input
Production_decision	2	I mainly have input or make all the decisions
Production_score	range 0-4	Sum 2 variables above
Resources_own_canoe	Y=1, N=0	Our household owns a canoe or boat which I use to harvest shellfish
Resources_decide_canoe	Y=1, N=0	I mainly decide when I use the canoe/boat for harvesting
Resources_member_credit	Y=1, N=0	A person in my household is a member of a savings and credit group, or has a bank account
Resources_decide_credit	Y=1, N=0	I mainly decide how much to borrow when I need credit
Resources_score	range 0-4	Sum 4 variables above
Income_decision		In my household, I am mainly the one who makes decisions about how to spend the money earned from shellfishing
Income_decision	0	I disagree strongly
Income_decision	1	I disagree a little bit
Income_decision	2	I agree a little bit
Income_decision	3	I agree strongly
Income_score	range 0-3	same as income_decision
Leadership_memb_assn	Y=1, N=0	Are you a member of the local women's organization or shellfishing association
Leadership_part_meet	Y=1, N=0	Have you participated in a meeting in the last year?
Leadership_speaking	Y=1, N=0	I am comfortable speaking in meetings to express my opinion.
Leadership score	range 0-3	

Variable name	Scoring/definition	
		Within 24 hours in the open fishing season, how many hours a day do you spend on:
Time_shellfish_travel	number in hrs	Traveling to and from the collection site
Time_shellfish_harvest	number in hrs	harvesting shellfish
Time_shellfish_process	number in hrs	shucking or processing shellfish
Time_shellfish_sell	number in hrs	selling shellfish
Time_total_hrs	number in hrs	Sum the total hrs.
Time_score	Y=1, N=0	If less than 10.5 hrs spent in shellfishing, workload is adequate, otherwise inadequate. Code as binary 1= adequate 0 = inadequate
WEAI_score	range 0-15	sum = Production_score + Resources_score+ Income_score + Leadership_score + Time_score

Scoring for governance variables:

Co management – management plan for shellfish area adopted by government authorities (local or national) that provides rights and responsibilities for decision making to shellfishers. Y/N (1/0)

Tenure – exclusive use rights granted (group or individual) to shellfishers that allows for excludability of others from outside the group. This can be formal via government or informal via traditional authorities. Y/N (1/0)

Traditional management – Traditional leaders/authorities involved in management in some manner – formal or informal, that supports shellfish harvesters rights and decision making Y/N (1/0)

Hypothesis 2

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
Shellfish Health		
Shellfish height	See Hyp 1 table above	dependent
Fishing mortality	See Hyp 1 table above	dependent
Exploitation ratio	See Hyp 1 table above	dependent
Shellfish health	See Hyp 1 table above	dependent
Shellfish health dichotomized	See Hyp 1 table above	dependent
Mangrove Habitat		
Mangrove habitat change	percent increase or decrease of mangrove area per site 2010-2020,	dependent/indep
Mangrove qualitative health	from June 2021 UCC site based research report - Table 1 Low, Medium, High - UCC expert opinion rank 0,1,2	dependent/indep
Mangrove Trajectory of Change between 2000-2010 & 2010-2020	Ordinal rank: slight decline, slight, modest or significant improvement: rank of 0-3	
Mangrove Governance		
Mangrove Shellfisher protection	Binomial Y/N (rules by shellfishers)	independent
Mangrove site legal protection	Binomial Y/N	independent
Women's empowerment score	See Hyp 1 table	independent
Pressure/threats score	Reduced Severity of pressure/threats score: (results of ICRAF Report 1 Tables 2-5 on threats and drivers on mangroves) Scoring per threat: High = 2, Medium = 1, low or NA = 0, all score summed for a range 0-34	independent

Mangrove Governance scoring

Mangrove Shellfisher rules – Do shellfishers protect mangroves via mgt plan regulations or informally by socially agreed consensus among shellfishers e.g. replanting/ no cutting rule If Y = 1 if N=0

Legal protection of mangroves by national law AND a local management plan for protecting or managing mangroves (e.g. RAMSAR plan for the site with mangrove protections) If Y = 1 if N=0

Hypothesis 3

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
Anemia Prevalence		
Hemoglobin concentration	Continuous: g/dl	dependent
Any anemia, Hb < 12 g/dl	Binomial/ Y N	dependent
Mild, Moderate, Severe anemia	Each a separate variable – binomial Y/N	dependent
Household Food Insecurity		
HFIAS score	Ordinal score	dependent
Food Secure	Binomial/ Y N	dependent
Mildly food insecure	Binomial/ Y N	dependent
Moderately food insecure	Binomial/ Y N	dependent
Severely food insecure	Binomial/ Y N	dependent
MDDW (total score, MDD achieved)	(Ordinal, binomial)	dependent
Dietary intake (Consumption)		
Total iron, zinc and oyster intakes		
Total iron, mg/d	Continuous: mg/d	independent
Total zinc, mg/d	Continuous: mg/d	independent
Total oyster, g/d	Continuous: mg/d	independent
Total iron and zinc intakes from oyster		
Iron intake, mg/d	Continuous: mg/d	independent
Zinc intake, mg/d	Continuous: mg/d	independent
Iron and zinc deficiency versus RDA	dichotomous	independent
Iron and zinc from oyster as percent of total		
Iron from oyster, percent	percent	independent
Zinc from oyster, percent	percent	independent
Income		
Household Food expenditure (ICRAF)	USD/day	independent
Wealth-Poverty score	Ordinal scale 1-10	independent
Household demographic variables		
Household size	Continuous: number of occupants	independent
Female headed household?	Binomial/ Y N	independent
Individual variable		
Age	Years - number	independent

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
Education	Total years schooling	independent
Household size	Total HH members	independent
Married	Binomial/ Y N	independent
Any Job	Binomial/ Y N	independent
Literate	Binomial/ Y N	independent
Wealth-poverty measure	Ordinal range 0-10 calculated by assigning a value of 1 (yes) or 0 (no) to each of 10 items (household ownership of a canoe + phone + TV + fan + refrigerator + LPG stove + main fuel used for cooking is gas + walls of house mainly made of cement + consumption in the last month of corned beef + purchase of eggs in the last month.) and summing the scores to give the total score	independent
Body Mass Index	Ratio, continuous	independent
Obese overweight/obese	Y/N, Y/N	independent

Hypothesis 4

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
Improved proximate landscape livelihoods and food systems		
Household diverse food system score	Ordinal (range 0-5) based on household question ICRAF survey # 7,11,15,18,23	independent
Other explanatory factors		
Number adults in household	Interval/integer	independent
Farm size	Continuous in acres.	independent
Yrs. you have farmed land	Interval/integer	independent
# visits to local markets	Interval /integer (r0-7)	independent
Distance to local market	Continuous in km.	independent
Improved mangrove habitat/ biodiversity		
Mangrove habitat change	(see Hyp 2 table)	dependent/indep
Mangrove qualitative health	(see Hyp 2 table)	dependent/indep
Mangrove Trajectory of Change between 2000-2010 & 2010-2020	(see Hyp 2 table)	
Mangrove percent cover change	(see Hyp 2 table)	Dependent/response
Reduced Severity of pressure/threats	?	
Pressure/threats score	Ordinal score (see Hyp 2 table)	Dependent/independent
Food Expenditures & Income from other livelihoods		
Livelihood dependency on shellfish	Ordinal bins of income ranges 0-6. see Hyp 1 table	Dependent/independent
Household per capita expenditure on food	Household in US$ See Hyp 1 table	Dependent/independent
NUTRITION		
MDD-W Score	See Hyp 3 table ordinal 0-10	Dependent/response

Variable Name	Measure/type	Variable type: dependent vs predictor/independent
MDD-W-Adequate	See Hyp 3 table binomial Y/N	Dependent/response
MAHFP (Months of Adequate Household Food Provisioning)	Number from 0-12 = number of months household had adequate food provisioning	Dependent/response