A new look into aquaculture interventions for improving productivity, income, nutrition and women's empowerment in low & middle-income countries: A systematic review update- preprint version

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About this systematic review

This systematic review updates the search and findings of a review of aquaculture interventions published in 2021. Both reviews are part of the 3ie Aquaculture Project, which was supported, in whole or in part, by the Gates Foundation (OPP1197415). The conclusions and opinions expressed in this work are those of the authors alone and shall not be attributed to the Foundation. Please direct any comments or queries to the corresponding author, Constanza Gonzalez Parrao, at cgonzalez@3ieimpact.org

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Contents

Background

Aquaculture production and demand continue to grow, with some low- and middle-income countries (L&MICs) emerging as key players. Global production expanded from 179 million tons in 2018 to 185 million tons in 2022 (the most recent year for which data is available; (FAO 2020b; 2024b). While production value over that time grew by over USD 50 billion, reaching USD 452 billion in 2022 (FAO 2020b; 2024b), consumption has also grown, from over 156 million tons in 2018 to 165 million tons in 2022 (FAO 2020b; 2024b). While the COVID-19 pandemic lockdowns disrupted production and supply chains, both demand and prices have rebounded (FAO 2024b). L&MICs have helped meet this demand. In 2022, L&MICs' total net trade for aquatic animal products reached USD 45 billion, outpacing net trade for all other agricultural products put together (FAO 2024b).

Aquaculture delivers an important food source in L&MICs, though its consumption varies regionally. Aquaculture production in Asia is positively associated with consuming aquatic foods, a trend that supports country-level findings that as local aquaculture grows, people living in poverty may consume more inexpensive farmed fish (Garlock et al. 2022). A shift to consuming aquatic foods could be promising for nutritional and environmental goals as aquatic foods are high in nutrition, and aquaculture generally has a lower environmental impact than livestock farming (Garlock et al. 2022; Troell et al. 2023). However, of all aquatic animal food consumed in 2021, low-income countries consumed only 2%, compared to almost one-quarter in middle-income countries and over half in upper middle-income countries (FAO 2024b). In contrast to the scenario in Asia, aquatic food consumption in Sub-Saharan Africa is low, where some countries have high food insecurity or malnutrition (Garlock et al. 2022).

Though recent development agendas promote aquaculture as a viable and greener alternative, aquaculture is generally overlooked by national policies. For example, the United Nations (UN) Food Systems Summit and the UN Framework Convention on Climate Change have highlighted how aquaculture can improve food security and environmental sustainability (FAO 2023; 2020a). In 2021, the Food and Agriculture Organization (FAO) adopted the Blue Transformation initiative, which aims to enhance aquaculture opportunities, improve food security and deliver sustainable choices, especially for women and small-scale farmers (FAO 2024b). However, aquaculture generally remains unrepresented in national policies, strategies and statistics to reduce poverty and eradicate hunger (Troell et al. 2023; Béné et al. 2016). For example, aquaculture may not factor into food systems, natural resources or health policies, while lack of data on the effects of local production could make aquaculture less of a priority (Troell et al. 2023). In turn, as Sub-Saharan Africa imports 1.5 times more fish than it produces through aquaculture, national policies to encourage investment and good practice could help to expand production (Ragasa, Charo-Karisa, et al. 2022).

While new evidence has emerged with recent aquaculture programs and practices, more information would provide insight about how to meet development goals. For example, studies in Myanmar and Kenya have considered the extent to which improved aquaculture practices or market access strengthened household food security and resilience during COVID-19 (Wang et al. 2024; Ochieng et al. 2024). However, questions remain about optimal ways to improve fish production and consumption, especially as researchers explore complex relationships between gender norms and diversifying practices and diets (A. Ahmed et al. 2024). The evidence base linking aquaculture with the Sustainable Development Goals is also insufficient, with more data needed to understand the contribution of aquaculture to ending hunger, reducing poverty, and improving health, livelihoods and gender equality (Troell et al. 2023).

In a systematic review of the effectiveness of aquaculture programs in L&MICs, Gonzalez Parrao, Shisler, et al. (2021) identified limited evidence, and the available data suggested that aquaculture programs may lead to small improvements in production value, income, expenditures, and food consumption. However, due to substantial heterogeneity and potential risk of bias in included studies, the authors advised caution in drawing strong conclusions from the results. There was also insufficient evidence to determine whether effects varied by gender, if there were spillover effects, or to compare cost-effectiveness across programs. Qualitative evidence highlighted that factors such as the program setup, participation, and the level of productive activities can influence the implementation and effectiveness of aquaculture programs. However, due to a lack of rigorous evidence and varied outcome measures, the authors were unable to extensively assess nutrition outcomes such as food security or diet quality. They were also unable to conclude about effects on women's empowerment.

With this systematic review update, we aimed to identify the latest evidence on aquaculture programs and examine whether the evidence (i) changed or filled existing gaps in our understanding of the effects of aquaculture interventions on productivity, income, nutrition, and women's empowerment, and (ii) gave insight into factors that affect pathways between aquaculture interventions and nutrition-related outcomes.

The intervention

We focused on aquaculture interventions that aim to increase productivity, income, nutrition and/or women's empowerment in L&MICs. We adopted FAO's definition of aquaculture as farming of aquatic organisms (including crustaceans, fish, and molluscs) and plants (including seaweeds and freshwater macrophytes) found in either inland or coastal areas. Farming relates to "the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated" (FAO 2024a, 188). We excluded interventions that only focused on capture fisheries (e.g., in marine water).

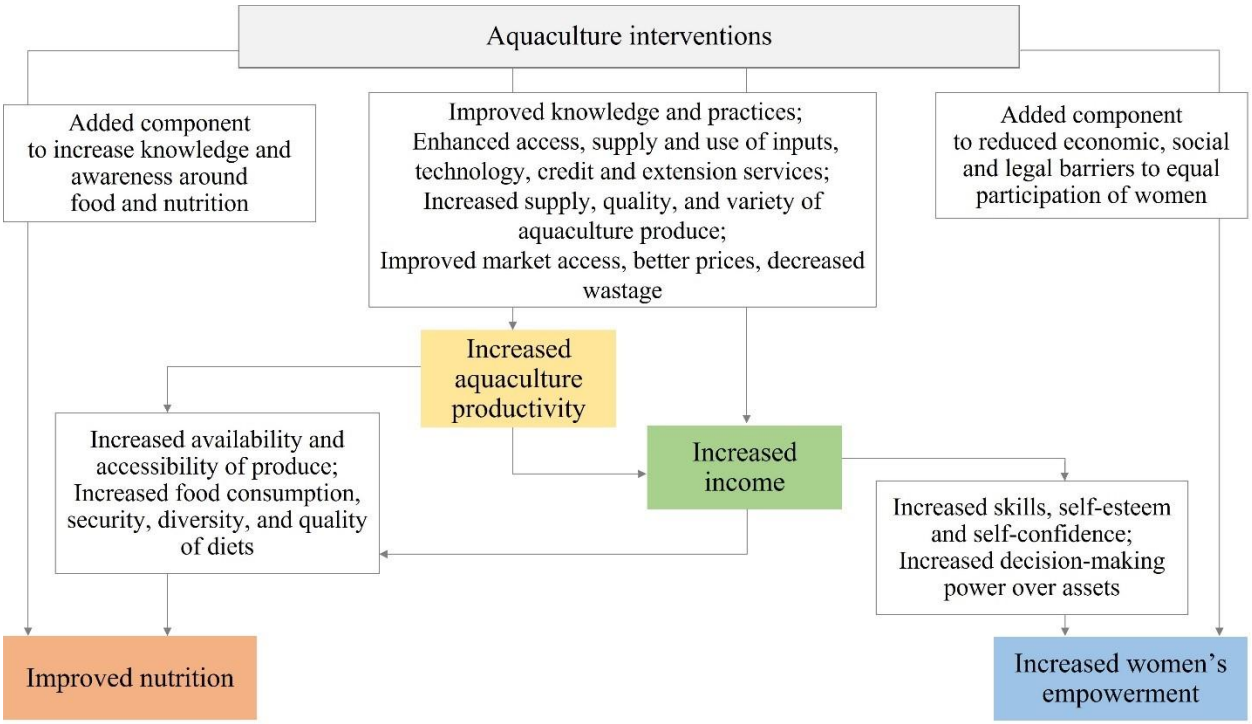
Drawing on the original review by Gonzalez Parrao, Shisler, et al. (2021), we defined aquaculture interventions as "any project, program, or policy aiming to provide new and/or improved activities at any stage of the aquaculture value chain". We included water-based and land-based aquaculture systems, as well as any type of aquaculture activities regardless of the scale of operations, turnover, hired labor, investments, and employed technologies. Other intervention activities may include delivering input supplies and services and strengthening production or access to markets. Most of these interventions aim to improve the quantity or quality of aquaculture products and ultimately increase income. In addition, interventions may include educational components to improve skills, build knowledge about nutrition, or promote gender empowerment. We therefore included interventions with components such as:

- Capacity and skill development interventions that aim to strengthen skills or introduce new practices among individuals and households. Activities could include individual training or community-based support.
- Behavioral change and nutrition interventions that aim to improve knowledge about healthy diets, such as incorporating fish and aquatic organisms.
- Gender equality and empowerment interventions to promote equal participation of women in the aquaculture sector.

How the intervention might work

The original systematic review protocol (Gonzalez Parrao, Moratti, et al. 2021) discussed extensively how aquaculture interventions can impact productivity, income, nutrition and women's empowerment, and these pathways are illustrated in Figure 1 (reproduced from the original review). By increasing knowledge or improving practices among the aquaculture value chain, producers may increase or optimize production and increase incomes. Aquaculture interventions could also potentially improve nutrition by increasing the availability of fish products and its consumption, as well as through better knowledge and awareness about nutrition. Finally, reducing barriers for women to participate in the aquaculture value chain could also have effects on women's participation, decision-making and empowerment.

Figure 1. Theory of change



Source: Gonzalez Parrao, Shisler, et al. 2021.

Why it is important to do this review

Several studies published since 2020 (when the original search was conducted) have evaluated relevant aquaculture programs, including in countries not covered by the original review. For example, two studies have evaluated aquaculture programs in Ghana, one providing training about aquaculture practices (Ragasa, Amewu, et al. 2022) and the other training about fish feed formulation (Ragasa, Osei-Mensah, and Amewu 2022). Other studies have evaluated the provision of materials and training on small-scale aquaculture in Myanmar (Dompreh et al. 2023) and an aquaculture loan support policy in Vietnam (Dao, Le, and Tran-Nam 2023). The review update also includes 3ie's recent impact evaluation of an aquaculture program implemented in Bangladesh.

The update of the 2021 review follows good practice in updating reviews over time and when new evidence is knowingly available (Smith and Ho 2023; Cumpston and Flemyng 2023). Given the limited evidence identified in the original review, updating the search and analyses remains relevant to understanding the effects of aquaculture interventions on income, productivity, nutrition, and women's empowerment outcomes. Through this review update, we can inform policy and practice on promoting aquaculture to further development goals, including improving livelihoods, gender equality, food security, and health.

Objectives

We addressed the following questions in this review:

1. Do aquaculture interventions increase the productivity, income, nutrition and empowerment of individuals engaged in aquaculture and their households in low- and middle-income countries?
2. To what extent do the effects of aquaculture interventions vary by intervention type, population group, and location? In particular, to what extent do effects vary by gender?
3. Do aquaculture interventions generate income and nutrition spillover effects beyond the farmers' households?
4. What factors influence the successful implementation of approaches to improve nutrition, dietary diversity or food security across aquaculture programs?
5. What is the cost-effectiveness of different aquaculture interventions focused on productivity, income, nutrition and empowerment outcomes?

Methods

The protocol for the original review (Gonzalez Parrao, Moratti, et al. 2021) detailed the study selection and analysis process (sections 3.1 to 3.3), which largely remained the same for the quantitative synthesis for this update. We followed best practices for conducting and reporting systematic reviews of effectiveness in international development (The Campbell Collaboration 2020; Waddington et al. 2012).

Criteria for considering studies for this review

The inclusion criteria for the review update retained most of the original criteria, with changes noted in Table 1 and further details presented in Appendix 1. Regarding types of studies, to reflect the latest best practices, we have explicitly differentiated and added quasi-experimental designs that robustly measured outcomes attributable to an intervention and with the use of an appropriate counterfactual. The review focused mainly on studies published after November 2020, when the original search was conducted. However, to minimize the risk of having missed studies in the original review, we searched for evidence from the original cut-off year (i.e., 1980) and cross-checked the results with the data from the original review. As with the original review, we excluded lab or efficacy studies that primarily examined biophysical mechanisms, such as fish height or weight, and studies conducted in a lab or tightly controlled settings. Due to a combination of limited resources and a focus on more recent evidence, we restricted the search for qualitative evidence to studies published from 2010 onwards.

Table 1. Inclusion criteria and modifications from the original SR

Criteria	Original review	SR update
Types of studies	Research questions (RQ) 1-3: Experimental designs Quasi-experimental designs: • Regression discontinuity designs • Natural experiments and instrumental variables estimation • Difference-in-differences, or fixed/ random-effects models with an interaction term between time and intervention • Interrupted time series or controlled interrupted time series • Statistical matching, covariate matching, coarsening, propensity score matching, propensity-weighted multiple regression analysis RQ 5: Studies or reports including unit or total costs for implementers, participants or non-participants	Research questions (RQ) 1-3: • Randomized controlled trials (RCTs) and quasi-RCTs • Natural experiments • Regression discontinuity designs (RDD) or fuzzy-RDD • Instrumental variables (IV) • Methods synonymous to the Heckman two-step model • Difference-in-differences (DID), two-way fixed-effects (TWFE), and two-way Mundlak regressions (TWM) • Interrupted time series (ITS) • Weighting and matching approaches • Synthetic control method RQ 4: studies of aquaculture programs with: • A clear research question/objective • Documentation of program design, implementation, context and/or (un)intended outcomes • Based on qualitative, descriptive quantitative, or mixed-methods designs, and process evaluations RQ 5: No change
Types of participants	Individuals, households, villages, municipalities, or community-based organizations in L&MICs	For RQ 4, we limited the scope to the 11 countries included in the quantitative synthesis
Types of interventions	Any project, program or policy across the aquaculture value chain	No change
Types of outcome measures	Primary outcomes: productivity, income, nutrition, and women's empowerment. Secondary outcomes (e.g., environmental) if identified	No change
Additional criteria	• Year of publication: 1980 onwards • Language: Any language • Publication status: Academic and grey literature	• Year of publication RQ 1-3, 5: 1980 onwards, with focus on new studies published after November 2020 RQ 4: 2010 onwards • Language: no change • Publication status: no change

Search methods for identification of studies

This section describes the search process we used to identify quantitative and qualitative evidence. We conducted a comprehensive search in both academic and grey literature sources.

Electronic searches

For quantitative evidence, we adapted the original review's electronic searches of academic and grey literature sites. Details about the original search can be found in section 3.2 and Appendix A of the review protocol (Gonzalez Parrao, Moratti, et al. 2021), while modifications to the academic and grey literature searches are noted in Appendix 2. For this review update, we incorporated additional academic databases and modified search terms based on feedback for the original review and guidance from the information specialist for the review update. For example, we searched dedicated databases for dissertations and theses and regional sources. As part of the search strategy update, we incorporated additional terms in the aquaculture concept terms, and updated search terms for study designs and L&MICs using the updated inclusion criteria. The final search strategy used to locate quantitative evidence consisted of four concepts: aquaculture, L&MICs, study designs, and outcome groups. Due to the addition of new terms to the search strategies, the searches were not limited to the search date of the previous review. The searches were limited to 1980 to July 21, 2024, and the search results were deduplicated across the various databases, and against the search results of the original review, using Covidence software (Veritas Health Innovation, n.d.). Appendix 3 provides the search strategies for identifying quantitative evidence.

For qualitative evidence, we conducted new electronic searches of academic and grey literature sites, based on the same set of academic databases as for quantitative evidence. We conducted two separate searches, one for qualitative evidence broadly, and a second focused on the programs located by the quantitative search. The general qualitative search strategy contained three concepts: aquaculture, 11 relevant countries, and qualitative study designs/data collection methods. The study designs concept was adapted from a pre-existing search filter (CDA 2024). The intervention-specific search was constructed from the intervention names and, in some cases, by combining program names and the countries where they were implemented. The qualitative searches were limited to 2010 to November 15, 2024. The search strategies are available in Appendix 4, accompanied by a brief search narrative (Cooper et al. 2018).

Search results from these sources were exported in RIS format and deduplicated. Deduplication was carried out within the interface (in the case of Ovid multifile searches, or by EBSCO discovery service), or externally using Covidence software.

We searched across 21 grey literature sources for quantitative evidence and across 19 of these sources for qualitative evidence, prioritizing those more likely to yield relevant results (Appendix 5 presents the sources and the approach for each). For 11 of these 19 sources, the search was limited by only aquaculture or related thematic terms. Hence, we considered the search results appropriate for screening qualitative evidence. We re-screened grey literature search results for sources where quantitative or thematic search terms did not limit the search strategy. For the remaining eight sources, we updated the search for qualitative studies from sources where quantitative terms were previously used or if they were strategically relevant grey literature sources. For example, we reran searches for sources that were limited to quantitative studies, such as CGIAR and ODI. Additionally, we did not utilize previous searches and conducted new searches for three key sources: FAO, USAID, and WHO. For most new or updated searches, we searched for aquaculture and nutrition terms to reduce irrelevant results.

Searching other resources

We conducted backward citation tracking for newly included quantitative studies, and forward citation tracking of all included studies identified in the original and updated reviews. For backward citation tracking, we manually reviewed the reference lists of included studies. We used Google Scholar to conduct forward citation tracking of included studies and the original review. We also published a call for studies in 3ie's newsletter circulated to all subscribers, and contacted key researchers to identify additional studies.

Data collection and analysis

The review update replicated the data collection and analysis approach from the original review (Gonzalez Parrao, Shisler, et al. 2021). Our analysis combined studies from the original review with new studies identified in this update. The following sections summarize our approach.

Description of methods used in primary research

To address research questions 1-3, we included primary studies that used experimental and quasi-experimental methods in line with the inclusion criteria. For the qualitative studies, we included qualitative, descriptive quantitative, and mixed-methods studies.

Selection of studies

We imported records into EPPI-Reviewer (Thomas et al. 2022) and removed remaining duplicates. For the quantitative studies, we did independent double screening at title and abstract[1] and at full text. All coders screened practice batches of studies until achieving 85% of consistency with the core team in terms of inclusion decisions.

We followed the same approach for the qualitative studies, also drawing from the latest Cochrane guidance for qualitative study selection (Ames, Booth, and Noyes 2024, 13–14). We screened studies for their use of primary data to explore pathways between aquaculture programs and nutrition, and with enough data for meaningful extraction (at least three lines of relevant text). We screened practice batches until reaching 85% agreement between coders and a core team member. To increase consistency, we double screened 600 records, reconciling with a core team member as needed. We prioritized studies that were most likely relevant for double screening at title and abstract, and after double-screening 15% (n = 1,129) of the records, we switched to single screening. All records were double-screened at full-text, resolving disagreements with a core team member as needed.

Data extraction and management

For quantitative studies, we used standardized forms to extract descriptive data, methodological data, quantitative data from outcome measures, and information about intervention design and implementation. For descriptive data, we single-coded studies with checks by a second reviewer (Appendix 6 presents the tool used). For quantitative data, we did independent double-coding, resolving disagreements with a core team member (Appendix 7 includes the tool used). We examined standardized effect sizes for outliers (defined as ± 3.29 SDs from the mean).

[1] We initially tried machine-learning models in EPPI-Reviewer to prioritize screening at title and abstract, but we ultimately did not use this tool as the model was unable to assign clear inclusion probabilities.

Assessment of risk of bias in included studies

To determine the extent that findings from each impact evaluation were reliable, we conducted a risk of bias assessment of estimates for all relevant outcomes. We appraised their internal validity and statistical conclusion validity using 3ie's risk of bias tools (see Appendix 8 for the tool used). We assessed the following criteria: assignment mechanisms, attrition, performance and motivation bias, biases in outcome measurement (such as recall bias), and reporting bias.

Two reviewers independently conducted the risk of bias assessment and resolved disagreements with a third reviewer as needed. We assessed each reported estimate and also assigned an overall rating for each study: high risk of bias, some concerns, or low risk of bias. For studies with different rates at the estimate level, we considered the lowest risk of bias rate.

Measures of treatment effect

We extracted data on effects and calculated standardized effect sizes to allow for comparison across studies where possible. For example, we calculated standardized mean differences (SMDs), variance, and standard errors for continuous outcomes that compared means across treatment and control groups, and we selected suitable approaches for calculating effect sizes based on data from included studies (Appendix 9 presents the formulas used). Pooled effect sizes were converted to mean differences where feasible.

Unit of analysis issues

We assessed studies for unit of analysis errors and, where identified, corrected them using intraclass correlation (ICC) coefficients (from the paper, where reported, or from other available data if required; see further details in Appendix 9).

Criteria for determination of independent findings

Dependent effects may exist for various reasons. To avoid double counting the same evidence, we identified linked publications and used effect sizes from the most recent publication where applicable. If a study used multiple model specifications, we selected the one preferred by the authors or, if a preferred model was not clear, the one with the most controls. When a study used multiple outcome measures for a particular construct, we used the measure that most accurately captured the construct without regard to the results reported.

To manage dependent effect sizes, we conducted additional data processing and selection based on criteria such as publication timeframe or outcomes reported; alternatively, we used robust variance estimation (RVE) analyses for outcomes sufficiently powered to do so. When studies had multiple treatment arms with the same control group, we calculated weighted average effects in separate meta-analyses by treatment construct; and where multiple treatment arms represent the same treatment construct, we calculated a weighted mean, standard deviation (SD) and merged effect size (Borenstein et al. 2009). Finally, if studies reported on the same program but for different samples, such as from different regions, we used estimates for all samples if measured relative to distinct comparison groups.

Dealing with missing data

We aimed to contact study authors to obtain missing or incomplete data that impeded us from calculating effect sizes.

Assessment of heterogeneity

To estimate the variability in the distribution of effect sizes, we assessed heterogeneity, including calculating the *Q* statistic, I^2, and τ^2., and also used forest plots. We followed the Cochrane Handbook (Higgins et al. 2024) to interpret heterogeneity levels. In addition, where possible, we conducted moderator analysis to identify potential sources of heterogeneity.

Assessment of reporting biases

We included relevant unpublished studies identified from searches and tested for the presence of publication bias using contour-enhanced funnel plots and statistical tests, when relevant.

Data synthesis

We meta-analyzed findings when at least two effect sizes were identified with similar outcome constructs and comparison approaches. We combined studies that evaluated the same type of intervention and measured the same type of outcome. We used inverse-variance weighted random effects to account for heterogeneity across interventions and contexts. We used R software (R Core Team 2022) packages to conduct meta-analyses: the metafor package (Viechtbauer 2010) for independent effects and the robumeta package (Fisher, Tipton, and Zhipeng 2023) for RVE analyses. We ran separate analyses for productivity, income, nutrition and women's empowerment outcomes, and subgroup analyses to explore heterogeneity across populations where data were available.

Subgroup analysis and investigation of heterogeneity

To examine heterogeneity and understand inequity in the context of aquaculture, we assessed 18 moderators categorized under geographical, contextual (e.g., climate shocks index, income group), intervention characteristics (e.g., program objectives, scale, and nature of targeted groups), and methodological and study characteristics (e.g., publication type, publication year). The full list of moderators considered in the meta-analyses is provided in Appendix 10.

We performed random effects meta-regression to explore the association between moderator variables and heterogeneity. We also conducted subgroup analyses to investigate heterogeneity by subgroups such as women and men, people in poverty or not in poverty, and other subgroups where data were available.

Sensitivity analysis

We assessed whether the meta-analysis results were sensitive to outliers, to any study being removed, and to excluding studies assessed as having a high risk of bias.

Treatment of qualitative research

To address research question 4, we used qualitative studies, descriptive quantitative studies, mixed-methods studies, and process evaluations that explored the connection between aquaculture programs and nutrition, dietary diversity, or food security in countries for which we found at least one impact evaluation of an aquaculture program. We assessed the quality of these studies using a modified version of the Critical Appraisal Skills Program tool (CASP 2011) across six domains: (i) defensibility of research design; (ii) appropriateness of sample; (iii) rigor of research conducted; (iv) credibility of research findings; (v) attentiveness to contexts; and (vi)

research reflectiveness. We did not assess domains five and six for quantitative descriptive studies. Appendix 11 presents the tool and approach used.

Studies were rated as critical, low, moderate, or high quality based on domain ratings, which ranged from one star (low) to four stars (high). We used a fatal flaw approach, in which we rated studies that failed to meet the assessment criteria in the first three domains as critical and dropped them from the qualitative synthesis. In addition, if any of the components of a mixed-methods study were rated critical, we excluded the study from the synthesis. One coder appraised each study, with the core team quality-checking 76% of appraisals.

To extract qualitative data, we developed a conceptual framework and data extraction tool drawing from relevant literature. We primarily adapted Kawarazuka and Béné's (2010) framework for pathways between fish production and household nutritional status, which, in turn, drew from UNICEF's conceptual framework for determinants of nutritional status. We also integrated a more recent version of UNICEF's framework (2021). While UNICEF's framework is sufficiently high-level to be applied to different contexts, Kawarazuka and Béné's framework is specific to aquaculture. In addition, while both frameworks discuss nutrition outcomes, research question 4 is not focused on the outcome level. Hence, we did not include this layer in the qualitative synthesis. Both frameworks chart a pathway from broader enabling conditions for good nutrition, such as economic resources or governance, to underlying determinants relatively specific to the household level, such as food security, to immediate determinants of nutritional status, including diet. Kawarazuka and Béné's approach outlines additional steps between aquaculture production, income generation, and nutritional status, while UNICEF's framework aggregates some of these categories (such as economic structures and household assets). This newer framework also includes gender norms as an enabling determinant, which is not explicitly considered in Kawarazuka and Béné's framework. Appendix 12 presents a visual summary of both frameworks and the determinants we adapted to organize our data extraction and analysis, and Appendix 13 presents our data collection tool, which includes definitions for these determinants.

For each study, we extracted publication information, program information, and factors related to either determinants of nutrition or program implementation. A single coder conducted data extraction, and a core team member checked 20% of the extracted studies for accuracy and consistency. Coders recorded data, or 'verbatims', under appropriate data extraction categories. The data extraction process was iterative; therefore, the core team regularly met with the coders, and changes to the data extraction strategy were informed by these discussions. Discussions and changes included easing the understanding of some framework categories to accommodate data from studies that would have been otherwise excluded.

Following data extraction, we focused on identifying factors relevant to determinants of nutrition, defined as aspects that studies highlighted could potentially contribute to dietary diversity, food security or nutrition among aquaculture program participants. These factors could be contextual and outside the direct control of the program, or could relate to participant, implementer or researcher perspectives about how the program was implemented. We then categorized factors into themes that are relevant to determinants of nutrition.

Treatment of cost data

To address research question 5, we collected economic data from our primary set of impact evaluations of included programs, and from additional sources located through supplementary reference searching. Our analytical framework followed recognized methodologies for

synthesizing economic evidence (Shemilt et al. 2008), encompassing complete economic assessments (such as cost-benefit, cost-effectiveness, and cost-utility studies) alongside partial evaluations (including cost analyses, comparative cost studies, and cost-outcome reporting), as well as related documents providing financial information about the reviewed interventions.

Study quality was evaluated by the research team with particular attention to both economic and effectiveness dimensions. We conducted a narrative synthesis of general economic information. For studies that reported costs and outcomes as distinct elements, we systematically captured resource use data, unit pricing, and aggregate costs to analyze these components together, focusing on comparable measures when available. Programs showing non-significant intervention effects were omitted from cost-effectiveness calculations, following established practice (Dhaliwal et al. 2013).

Given the methodological limitations observed across this body of literature, we employed a Cost Data Quality Assessment framework, adapted from Acharya et al. (2024), to evaluate the reliability of economic findings. A five-level classification system provides criteria to evaluate the completeness and precision with which program expenditures are documented in individual studies (a detailed tool is provided in Appendix 14). The rating scale spans studies employing detailed resource-based costing approaches (highest quality) to those relying solely on aggregate budget data (lowest quality). This approach enables clearer communication about the quality of our evidence base while identifying areas that require enhanced economic methodology in aquaculture research.

Summary of findings and assessment of the certainty of the evidence

We did not plan to include summary of findings and assessment of the certainty of the evidence.

Results

In this section, we first provide an overview of the characteristics of the studies and aquaculture interventions included in the review. We then discuss the risk of bias of included impact evaluations, followed by the results of the quantitative, qualitative, and cost evidence analyses.

Description of studies

Results of the search

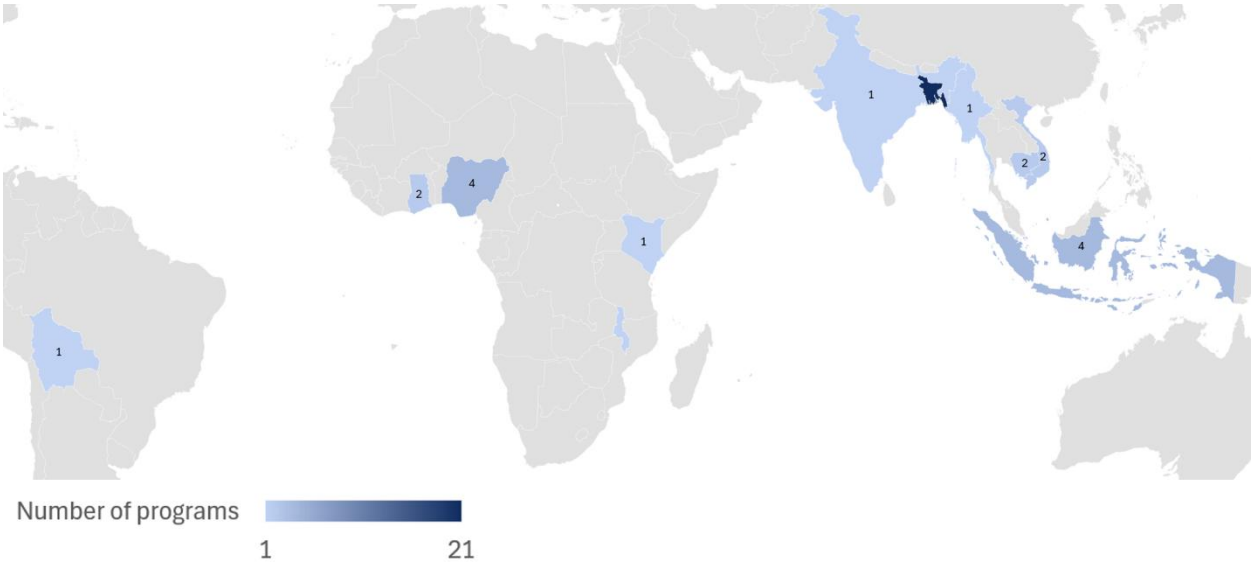
The PRISMA flowchart (Appendix 15) shows the results of our searches to identify studies for research questions 1-4. From our searches between July and November 2024 and from the original search conducted in November 2020, we identified 19,617 records to support the updated review's qualitative research question. After removing duplicates, we screened 18,194 records based on their title and abstract. Ultimately, we included 76 new records in our review update: 36 quantitative and 41 qualitative records. These records are in addition to the 21 quantitative records included in the original review, which are not shown in the PRISMA flowchart in Appendix 15 (the original review provides details of its search results; Gonzalez Parrao, Shisler, et al. 2021). In this updated search, we also found studies published before 2020 that were not identified in the original review. Details of these studies are presented in Appendix 16.

Included programs

Of the 36 included studies, 28 are unique impact evaluations, while the remaining eight are studies linked to a program already identified for inclusion. The new search added 31 studies covering 27 programs. Ultimately, this review update covers a total of 57 studies of 40 programs. Appendix 17 presents the main characteristics of these 40 programs, including name, description, funder, study design, comparison group, and reported outcomes.

We found an increase in the number of published impact evaluations in the past five years (23 of the 57 evaluations reviewed were published in 2021 or later). Figure 2 presents the geographical distribution of included programs. Most of the programs with rigorous evaluations continue to be from Bangladesh (n = 21). However, we identified programs from new regions (e.g., Bolivia) and from countries that were not identified in the original review. We found four programs each from Indonesia and Nigeria, followed by two programs each from Cambodia, Ghana, and Vietnam, and one program each from Bolivia, India, Kenya, Malawi, and Myanmar. Hence, most of these programs were implemented in lower-middle-income countries (n = 22), while the others were conducted in low-income countries. We did not find programs implemented in upper-middle-income countries.

Figure 2. Geographical distribution of included programs



We classified countries based on their risk of exposure to climate shocks, such as earthquakes, droughts, and sea level rise, as defined by the World Risk Index (BEH, n.d.) and based on the first year of program implementation or the earliest year available. Most programs were implemented in countries with a 'very high' exposure to climate shocks (n = 29), including in 21 in Bangladesh, four in Indonesia, and two in Cambodia and Vietnam. Three programs were from countries with a 'high risk': two from Ghana and one from Malawi. Seven programs were implemented in countries with 'medium' exposure: four in Nigeria and the remainder in India, Kenya, and Myanmar. The Camellones program in Bolivia was the only one with 'very low' risk.

Participants

Table 2 captures the demographic profile of the population targeted by the programs, although studies did not usually or clearly report this information. Most programs targeted both women

and men (n = 26), four programs explicitly targeted women (Agribusiness BGD, BS, Ecoponds, and FOF), one program was designed for men (Microcredit BGD 2), and nine programs did not provide this information. Most programs did not provide information on the participants' age and socioeconomic status. Only Agribusiness BGD and FOF targeted women aged 18-55 and 18-45, respectively, and 20 programs targeted participants from a low socioeconomic background.

Most programs were carried out in rural areas (n = 29), one program reported a focus on both rural and urban areas (Camellones), while for 10 programs we did not find their location. Thirty-three programs were practiced on land, seven programs did not explicitly provide this information. While three programs targeted landowners (DSAP, IAA, and MAEP), and four targeted nonowners (AFP, BS, Camellones, and CBFC), and two programs targeted both owners and nonowners (Fadama III and GNAEP), for most programs we did not find if participants owned the land where they practiced aquaculture (n = 31).

Interventions

We assessed how each program addressed our **theory of change**. All aquaculture programs focused on improving income and productivity (n = 40), with some also having an added focus on women's empowerment (n = 18) or nutrition and health (n = 13). In terms of the interventions' **scale** of their operation, we found that two programs were implemented at a national level (Fadama III and Agribusiness BGD), while most were implemented at the subnational level (n = 28) or within a region in a country (n = 10). We also classified programs based on their **target** level: for 17 programs, activities were focused on individuals, for 13 programs these were delivered at a community level, and we were not able to categorize 10 programs. Ponds were the most common **aquaculture system** in which programs operated, followed by rice fields, cages, and other systems. We identified four other types of aquaculture systems: camellones, an indigenous land management system; ditches; seasonal floodplains; and juvenile prawn nursing. Six programs did not specify this information.

We examined specific activities from included programs. The provision of **training or learning opportunities** for participants to develop skills was the most common program activity, reported in 29 programs. The training offered by programs varied in content and scope. For example, ANGel provided training to farmers on a variety of topics, such as cultivating crops, raising poultry and sheep, and taught farmers about fishpond cultivation while integrating nutritional content into the training. This program involved both husbands and wives to encourage women's participation. In contrast, CCDP trained aquaculture groups on aquaculture installations to ensure safe and sustainable harvesting. Participants also received training on producing processed fish products, financial management, and capacity building on sales and transactions. Other training content included, for example, sessions on better management practices and nutrition-sensitive training (MYSAP), fish farming and marketing (Camellones), use of feed and fishing gear, and sessions on value chain and market systems (Ecoponds).

We identified two activities as the second most frequent: providing farmers with **post-production support** and **access to technology**, each reflected in 21 programs. Examples of post-production support included, for example, improved access to better markets and upgraded transport infrastructure (CCRIP), shrimp and fishery product certification (CBIB), and post-program networking through a WhatsApp group (TiSeed). Examples of programs that provided technology to create and/or rehabilitate aquaculture systems included, for example, provision of aquaculture installations (CCDP), introduction to technologies through demonstration sites (EJ, NG, and HARVEST), and introduction to quality lab testing methods to analyze shrimps for antibiotic residues (Training VNM).

Twenty programs reported on the provision of **long-term technical assistance**, offering materials and guidance (e.g., by extension workers in the field). This differs from training, which is typically a short-term activity. For example, Ecoponds ensured continuous support by establishing learning centers where extension personnel were accessible, and by training lead farmers who, in turn, trained other farmers alongside extension workers. HARVEST provided intensive technical assistance to clients for 18-24 months, while IDEA trained service providers in the area to deliver extension services to farmers, similar to AGEP.

Participants in 15 programs were granted **access to credit** to enhance farmers' involvement along the value chain. Examples of types of credit support reported included, for example: farm owners obtained loans for up to VND 2 billion for aquaculture in Loan VNM; participants in group savings schemes within CCDP received loans from the group when needed, and a range of NGOs provided microcredits in Microcredit BGD1, Microcredit BGD2, Microcredit BGD3, and Agribusiness BGD.

Finally, 14 programs provided **direct resources** (e.g., fish seed, fingerlings) to support fish production. For example, inputs were supplied in CCDP, IDEA, and MYSAP. In turn, SSFF supplied feed to farmer groups while establishing feed production units at the farmer level to ensure access to quality fish feed using locally sourced materials and promote self-sufficiency.

Outcomes

We identified outcomes reported across the four main groups: income (n = 43), nutrition (n = 21), productivity and production (n = 17), and women's empowerment (n = 13). The most common outcome measures reported were total household income (n = 19), production volume (n = 14), income from fish or farm (n = 14), and total expenditure (n = 14). More studies reported established measures related to nutrition and women's empowerment compared to the original review. For instance, five studies measured the Household Dietary Diversity Score (Swindale and Bilinksy 2006), three studies reported the Food Consumption Score (WFP 2008), and six studies reported the Women's Empowerment in Agriculture Index (Alkire et al. 2013). We also aimed to identify other outcomes from eligible studies not captured in our primary outcome groups. However, additional outcomes were not reported across included studies.

Study designs

Most of the included studies employed quasi-experimental designs to evaluate aquaculture interventions (n = 46). Eleven employed randomized study designs (n = 6 at the cluster level and n = 5 at the individual level). Among quasi-experimental designs, the most common approach was propensity score matching (PSM; n = 18), followed by a combination of PSM and difference-in-difference estimations (n = 9).

Excluded studies

We excluded most records based on their title and abstract, mainly due to not evaluating an intervention, being efficacy studies, or qualitative studies that did not focus on human nutrition or food security. Not evaluating an intervention or not having a valid study design were the most common reasons for exclusion when looking at the quantitative studies' full text. In turn, we mostly excluded qualitative studies because they did not focus on aquaculture or did not explore an aquaculture intervention. Appendix 15 shows a detailed breakdown of the reasons for exclusion, while Appendix 18 provides examples of studies excluded at full text screening.

Table 2: Main characteristics of included programs

Program	Targeted participants			Program scope			Value chain components						ToC pathways			
	Sex	Age	Socioeconomic status	Scale	Aquaculture system	Aquaculture Product(s)	Training	Technology Provision	Direct Resources	Credit	Technical Assistance	Post-production Support	Productivity	Income	Nutrition	Women's empowerment
AFJ	Both			Sub-national	Ponds, Cages	Tilapia, catfish	✓				✓		✓	✓		
AFP	Both		Low	Sub-national	Rice fields	Crab, snails, swamp eel		✓	✓	✓		✓	✓	✓		
AGEP	Both		Low	Sub-national	Ponds	Fish	✓				✓	✓	✓	✓	✓	✓
Agribusiness BGD	Women	18-55	Low	National		Fish	✓			✓		✓	✓	✓		✓
ANGeL	Both			Sub-national	Ponds	Fish	✓					✓	✓	✓	✓	✓
ASPS II	Both		Low	Sub-national	Ponds	Fish	✓				✓	✓	✓	✓	✓	
BS	Women		Low	Local	Ponds		✓	✓		✓	✓		✓	✓		✓
CADP	Both			Sub-national		Fish		✓			✓	✓	✓	✓		✓
Camellones	Both			Local	Camellones	Fish	✓			✓	✓	✓	✓	✓		
CBFC				Sub-national	Seasonal floodplains	Indian major carps, and exotic carps		✓	✓				✓	✓	✓	
CBIB				Local	Ponds	Shrimp						✓	✓	✓		
CBNRM			Low	Sub-national	Rice-fields	Fish			✓		✓	✓	✓	✓		

Program	Targeted participants			Program scope			Value chain components						ToC pathways			
	Sex	Age	Socioeconomic status	Scale	Aquaculture system	Aquaculture Product(s)	Training	Technology Provision	Direct Resources	Credit	Technical Assistance	Post-production Support	Productivity	Income	Nutrition	Women's empowerment
CBNRMP-ND	Both		Low	Local	Ponds	Fish	✓			✓		✓	✓	✓		✓
CCDP	Both		Low	Sub-national		Fish	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CCRIP	Both		Low	Sub-national		Fish						✓	✓	✓		✓
CSISA-BD	Both			Sub-national	Ponds, Rice fields	Fish (carp, tilapia, mola), fresh/brackish water prawn, shrimp	✓		✓		✓	✓	✓	✓		
DSAP	Both		Low	Sub-national	Ponds, rice fields		✓	✓		✓	✓		✓	✓	✓	✓
Ecoponds	Women			Sub-national	Ponds	Fish	✓				✓	✓	✓	✓		✓
EJ	Both		Low	Sub-national	Ponds	Fish	✓	✓			✓		✓	✓		✓
ESP				Sub-national	Ponds	Tilapia, catfish		✓	✓	✓			✓	✓		
Fadama II	Both		Low	Sub-national	Ponds	Catfish, tilapia	✓	✓	✓		✓		✓	✓		
Fadama III	Both			National	Ponds	Catfish	✓	✓	✓				✓	✓		
FOF	Women	18-45	Low	Local	Ponds	Small fish and large fish	✓	✓	✓		✓		✓	✓	✓	✓
FPO	Both			Local	Ponds	Fish	✓		✓				✓	✓		
GNAEP	Both		Low	Sub-national	Ponds, cages, rice fields and	Prawn, carps, small indigenous fish	✓	✓		✓			✓	✓	✓	✓

Program	Targeted participants			Program scope			Value chain components						ToC pathways			
	Sex	Age	Socioeconomic status	Scale	Aquaculture system	Aquaculture Product(s)	Training	Technology Provision	Direct Resources	Credit	Technical Assistance	Post-production Support	Productivity	Income	Nutrition	Women's empowerment
					juvenile prawn nursing											
HARVEST	Both		Low	Sub-national	Ponds	Fish	✓	✓		✓	✓	✓	✓	✓	✓	✓
IAA				Sub-national	Ponds		✓	✓					✓	✓	✓	
IDEA				Sub-national	Ponds	Fish	✓	✓	✓		✓	✓	✓	✓	✓	✓
Loan VNM	Both			Sub-national		Fish, shrimp				✓			✓	✓		
MAEP	Both			Sub-national	Ponds	Fish	✓						✓	✓		✓
Microcredit BGD1			Low	Local	Ponds	Fish				✓		✓	✓	✓		
Microcredit BGD2	Men		Low	Sub-national		Fish	✓			✓			✓	✓		
Microcredit BGD3	Both		Low	Local	Ponds	Fish				✓			✓	✓		
MYSAP	Both		Low	Sub-national	Ponds	Fish	✓	✓	✓		✓		✓	✓	✓	
NG	Both		Low	Sub-national	Ponds	Fish	✓	✓			✓	✓	✓	✓		✓
SAFAL	Both			Sub-national	Ponds		✓	✓				✓	✓	✓	✓	✓
SMART-Fish				Sub-national	Ponds, cages	Fish and seaweed	✓	✓	✓		✓	✓	✓	✓		

Program	Targeted participants			Program scope			Value chain components						ToC pathways			
	Sex	Age	Socioeconomic status	Scale	Aquaculture system	Aquaculture Product(s)	Training	Technology Provision	Direct Resources	Credit	Technical Assistance	Post-production Support	Productivity	Income	Nutrition	Women's empowerment
SSFF				Local	Ponds	Catfish		✓	✓				✓	✓		
TiSeed	Both			Sub-national	Ponds, cages	Tilapia, Catfish	✓				✓	✓	✓	✓		
Training VNM	Both			Local	Ponds	Shrimp	✓	✓		✓			✓	✓		

Note: Cells shaded in grey indicate that such information was not provided or was not clear in the papers. Additional information on included programs is presented in Appendix 17.

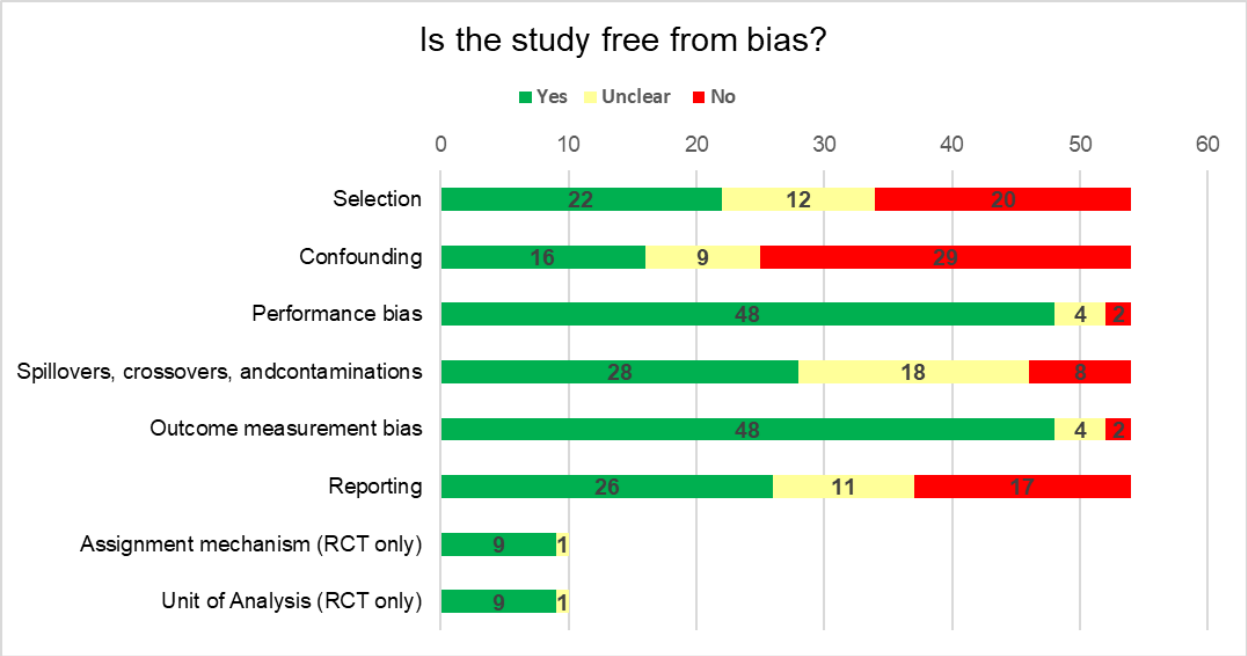
Risk of bias in included studies

We conducted risk of bias assessments at the estimate level to assess the quality of included studies and identify potential sources of bias. We assessed a total of 53 studies, one of which reported on two distinct programs: MAEP and GNAEP (DANIDA 2008). We therefore conducted 54 separate assessments, appraising 1,417 estimates from 44 studies based on quasi-experimental designs and 10 randomized evaluations.[2]

We found a high risk of bias in most of the evidence (k = 997, 71% of all estimates). Less than a third of the estimates were assessed as having some concerns (10%) and low risk of bias (19%). This trend is driven by studies with quasi-experimental designs: 88% of these estimates were rated as having high risk of bias (k = 997), while the rest was appraised as having some concerns of bias (k = 140). In contrast, 98% of the estimates from experimental designs were assessed as having low risk of bias (k = 271), with only five estimates displaying some concerns of bias. Appendix 19 presents the full assessment for each study included in the review.

For each bias dimension, we asked whether the study is free from such bias. At the study level, most evaluations were ranked as having an overall high risk of bias (n = 36), nine displayed some concerns, and nine were graded as low risk of bias. Figure 3 shows that the dimensions with the most issues relate to confounding factors and selection bias.

Figure 3. Summary of the risk of bias assessment by dimension



Regarding confounding factors, we investigated whether authors adequately executed the method of analysis to ensure comparability of groups and whether they controlled for factors that could have affected the results. The appraisal indicated that 29 studies did not properly

[2] We did not perform risk of bias assessment of the four studies that were excluded from the meta-analysis due to missing or incomplete information to calculate effect sizes.

account for confounding factors or did not report information about group comparability. For example, the covariates employed for matching were not equated between the treatment and comparison groups (Dam Lam et al. 2022). In other instances, studies did not provide information on the matching of covariates (Mahmud, Haque et al., 2022) or used difference-in-difference methods without discussing parallel trends assumptions and attrition (DANIDA 2011).

Regarding selection bias, we assessed whether the allocation or identification mechanisms employed in the studies could effectively control for selection bias. We identified studies that failed to report information about the covariates used for matching (Haque et al. 2025; DANIDA 2011; Tijani, Masuku, and Raufu 2014). Other issues included studies not controlling for unobservable characteristics or that failed to address selection bias beyond observable factors (Syed et al. 2024), and studies that compared randomly selected participants to purposively selected comparison groups (Etuk and Ayuk, 2021).

Synthesis of results

We present three sections. First, we present the findings from the meta-analyses to assess the effectiveness of aquaculture interventions. Second, we draw on qualitative evidence to identify barriers and facilitators to improving nutrition and food security among intervention participants. Third, we describe and discuss the cost evidence of the included aquaculture interventions.

Quantitative synthesis

This section presents the findings of the meta-analysis based on 1,417 estimates from 54 studies[3] reporting on 40 programs (45 treatment constructs[4]). The results are presented along the four main outcome domains: productivity, income and livelihoods, nutrition, and women's empowerment. Within each domain, we present outcomes as reported in the studies.[5] For each outcome analyzed, we present the average weighted effect computed with the random-effects model or, where possible, the RVE model. We then discuss sources of heterogeneity identified through moderator analyses, and the results of the sensitivity analyses and publication bias tests. Additional results and figures are included in Appendix 20.

1. Productivity

Our analyses indicate that aquaculture interventions significantly increased an aggregated measure of production volume and specific outcomes of fish yield and fish density. We did not find statistically significant effects on production value and quality.

Production volume (aggregated measure)

Studies reported on a variety of measures on production volume, including for example, fish Kg/land; fish Kg/time/land; tons of fish produced; feed conversion ratio; fish kg produced in the last 12 months; and total factor productivity. Given the heterogeneity of these measures, we conducted an RVE model with an aggregated measure of production volume, which included 69

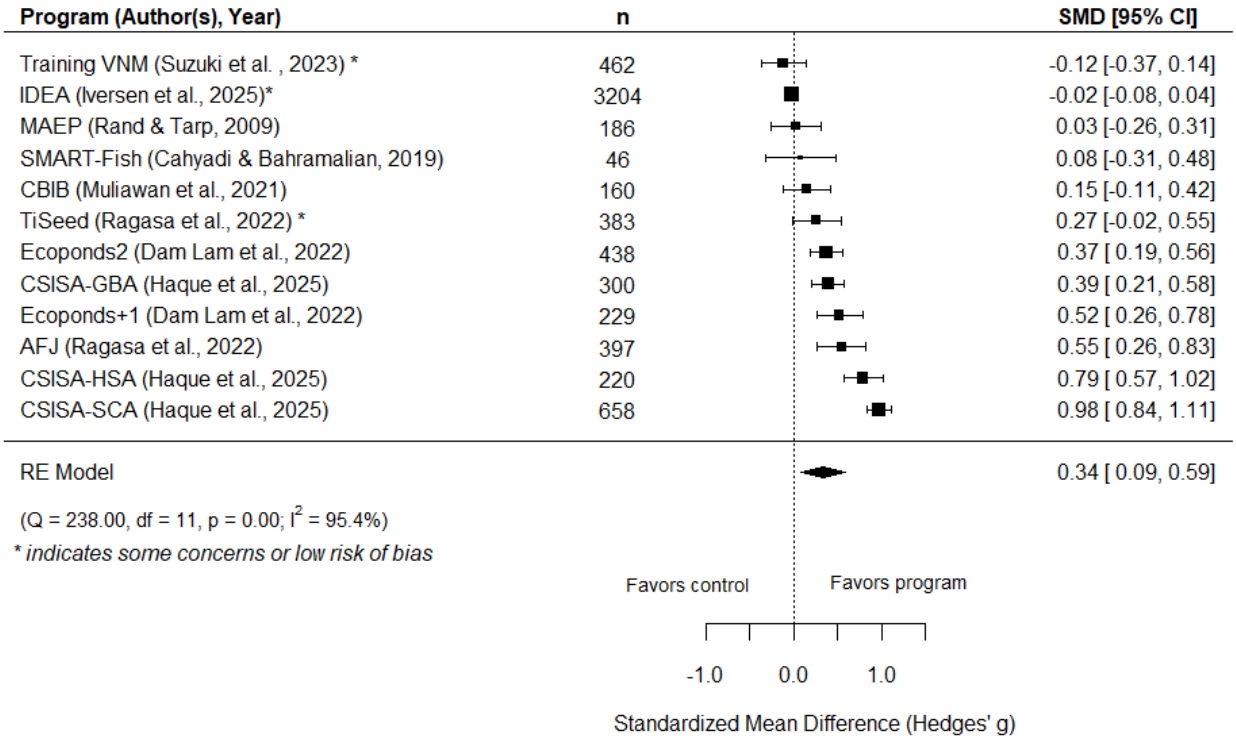
[3] Despite contacting the authors, we could not include four studies due to missing data (Hallman, Lewis, and Begum 2007; N. Kumar and Quisumbing 2010; Amankwah 2016; Suzuki and Nam 2023).
[4] Haque et al. (2025) reported on the CSISA-BD program using three different samples; Tijani, Masuku, and Raufu (2014) reported on the Fadama II program using three distinct samples; and Dam Lam et al. (2022) reported on the Ecoponds program using two different samples.
[5] We synthesized outcomes assessed in at least two programs; hence, we could not explore: global dietary quality score (GDQS), nutrients intake, blood measures, and total gender attitude score.

estimates from 15 studies reporting on 17 programs. We found that aquaculture programs led to a large and significant increase in aggregated production volume ($\widehat{SMD}$ = 0.44, 95% CI [0.19 to 0.70], p = .002), which showed considerable heterogeneity (I^2 = 93.88%). The moderator analyses indicated that programs that provided additional non-aquaculture components (such as integrating women in other productive value chains) appeared to be less effective ($\hat{\beta}$ = -0.20, p = .49) than interventions focused uniquely on aquaculture. Moreover, estimates derived from RCTs and those assessed as having low risk or some concern for risks of bias showed smaller effects compared to estimates from quasi-experimental designs and those with high risk of bias ($\hat{\beta}$ = -0.36, p = .04). However, these two moderators are collinear and, thus, it is challenging to establish what is driving this result.

Fish yield

We initially included 9 studies reporting on 13 programs (or treatment arms) in this analysis and found that aquaculture programs drove a large and significant increase in fish yield ($\widehat{SMD}$ = 0.48, 95% CI [0.18 to 0.79], p < .01). After removing an influential outlier (Dompreh et al. 2023), the average effect decreased in size ($\widehat{SMD}$ = 0.34, 95% CI [0.09 to 0.59], p = .01, Figure 4) and showed considerable heterogeneity (I^2 = 95.38%). We assessed three of these estimates as having low risk or some bias concerns. We did not detect funnel plot asymmetry, suggesting there is no publication bias for this outcome. The moderator analyses revealed two colinear moderators, which prevents us from identifying the exact source of variation: estimates from experimental studies and those assessed as low risk or some concern for risks of bias were associated with smaller effects compared to estimates from quasi-experimental designs and those assessed as high risk of bias ($\hat{\beta}$ = -0.41, p = .04).

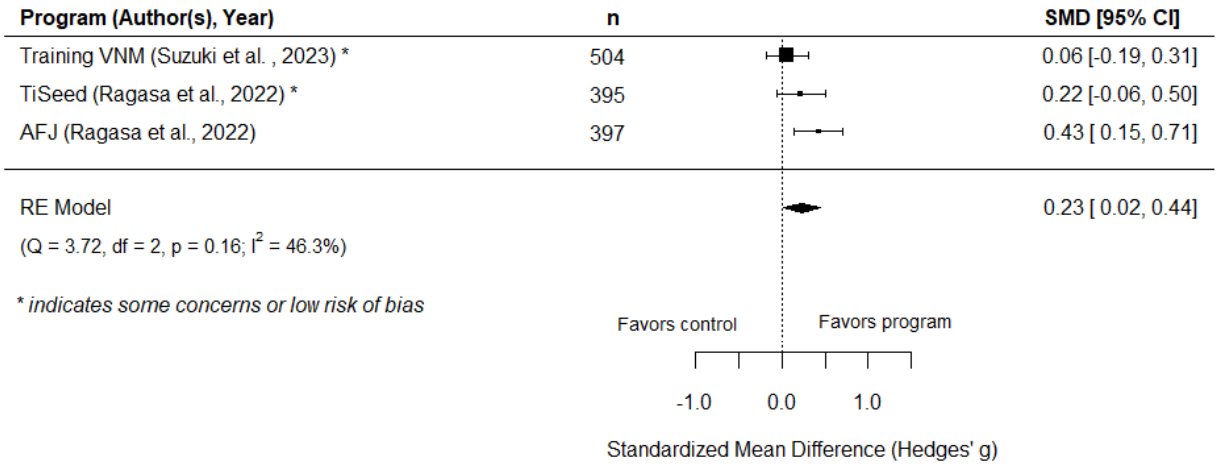
Figure 4: Forest plot of meta-analysis on fish yield



Fish density

We included three programs in this analysis. We found that aquaculture interventions led to moderate improvements in fish density ($\widehat{SMD} = 0.23$, 95% CI [0.02 to 0.44], *p* = .04; Figure 5), showing moderate heterogeneity ($I^2 = 46.28\%$). The sensitivity analyses indicated that the size of the average effects fluctuated between small ($\widehat{SMD}$ = 0.13) and moderate effects ($\widehat{SMD}$ = 0.24). There was insufficient evidence to conduct moderator analyses or publication bias tests.

Figure 5: Forest plot of meta-analysis on fish density



Production value and quality

We included four programs in the analysis of production value, and three programs when analyzing production quality. We found that aquaculture interventions did not have a significant effect on either outcome (production value: $\widehat{SMD} = 0.10$, 95% CI [-0.05 to 0.25], *p* = .20; production quality: $\widehat{SMD} = -0.11$, 95% CI [-0.35 to 0.12], p = .34; Appendix 20).

The moderator analyses for production value indicated that interventions that provided direct resources were associated with larger effects ($\hat{\beta}$ = 0.25, *p* = .01) compared to other components along the aquaculture value chain. In turn, while the sensitivity analyses corroborated the result on production quality, insufficient evidence prevented us from conducting statistical moderator analyses and publication bias tests for this outcome.

2. Income and livelihoods

We found that aquaculture interventions significantly improved an aggregated measure of income, as well as total household income, profits, and revenues, but did not have an effect on total or food expenditures. While we did not identify significant effects for the aggregated measure of assets or land area, we found that aquaculture programs significantly increased productive assets, such as fishing or agricultural assets. Lastly, we did not identify statistically significant effects on poverty headcount ratio or market participation, but we found that aquaculture interventions significantly improved prices received from aquaculture activities.

Income (aggregated measure)

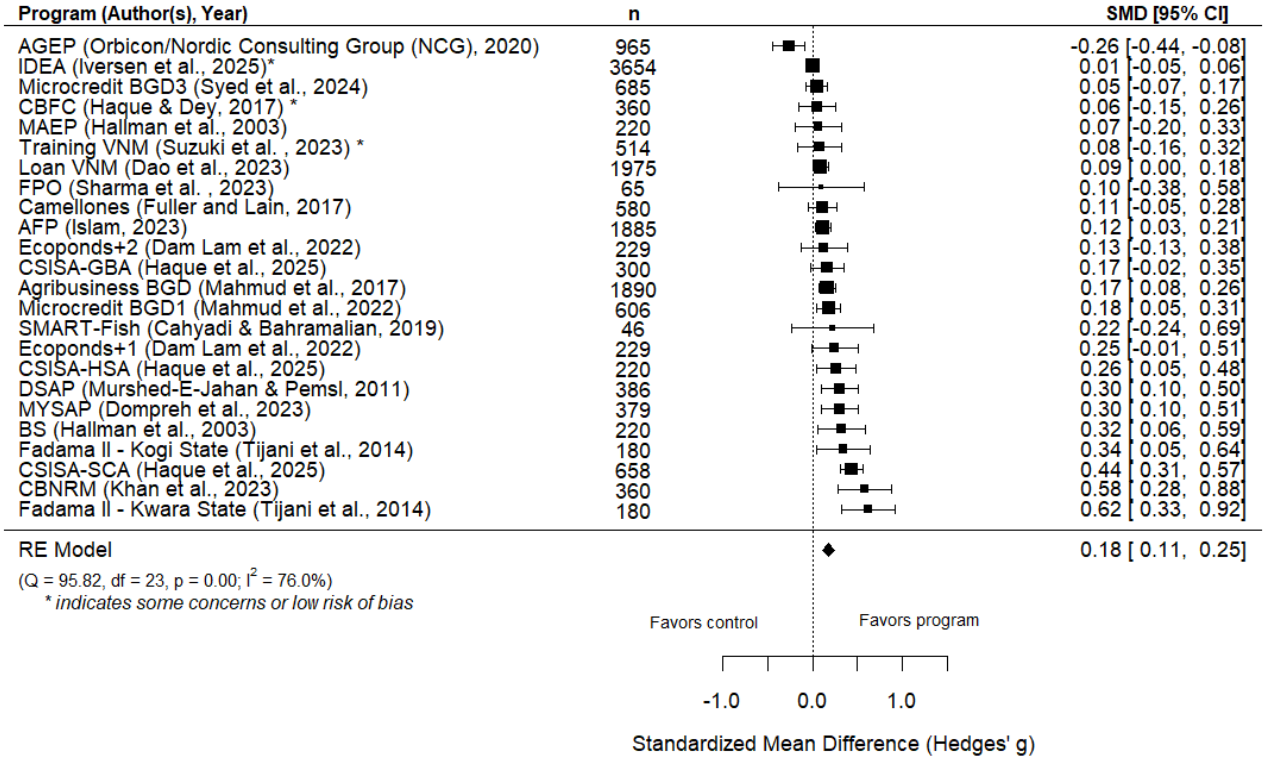
We included 221 estimates from 31 studies reporting on 30 programs. These studies reported a variety of measures, for example: fish income, non-fish income, household income from women's activities, gross/net household income per capita, gross income per capita, total

household income, and wage income. Given the diversity of measures, we ran an RVE model for an aggregated measure of income, which showed that aquaculture programs led to a significant increase in income ($\widehat{SMD}$ = 0.24, 95% CI [0.15 to 0.34], p < .001) with considerable heterogeneity (I² = 89.23%). We did not find statistically significant moderators for this outcome.

Total household income

We included 19 studies reporting on 24 programs in this analysis. We found that aquaculture interventions brought a small increase in total household income ($\widehat{SMD}$ = 0.18, 95% CI [0.11 to 0.25], p < .001), showing moderate heterogeneity ($I^2 = 76.00\%$).[6] This result was corroborated by the sensitivity analyses. We did not detect publication bias. We assessed three of the 24 estimates as having low risk or some concerns of bias. The moderator analyses showed that programs from Asian countries ($\hat{\beta}$ = -0.32, p = .03) and those implemented in countries with very high exposure to climate shocks ($\hat{\beta}$ = -0.21, p = .048) had smaller effects compared to programs implemented in African and Latin American countries, or in countries less exposed to climate shocks. Conversely, programs implemented in Nigeria showed larger effects ($\hat{\beta}$ = 0.23, p = .03) compared to other countries. Estimates from peer-reviewed articles were larger ($\hat{\beta}$ = 0.18, p = .02) than effects reported in grey literature manuscripts. Lastly, the size of the effects on income marginally diminished as the program size ($\hat{\beta}$ < -0.001, p < .01) and the length of the evaluation period ($\hat{\beta}$ = -0.01, p < .001) increased.

Figure 6: Forest plot of meta-analysis on total household income



[6] We also found that aquaculture programs have a large effect on income from fish or farm activities. Details of this result are presented in Appendix 20.

Total and food expenditure

We analyzed expenditures through two outcomes: total expenditure, for which we included 14 studies reporting on 16 programs, and food expenditure, for which we included five programs. We found that aquaculture programs did not significantly affect either expenditure measure (total expenditure: $\widehat{SMD}$ = 0.01, 95% CI [-0.11 to 0.13], p = .91; and food expenditure: $\widehat{SMD}$ = 0.09, 95% CI [-0.03 to 0.22], p = .15; Appendix 20).

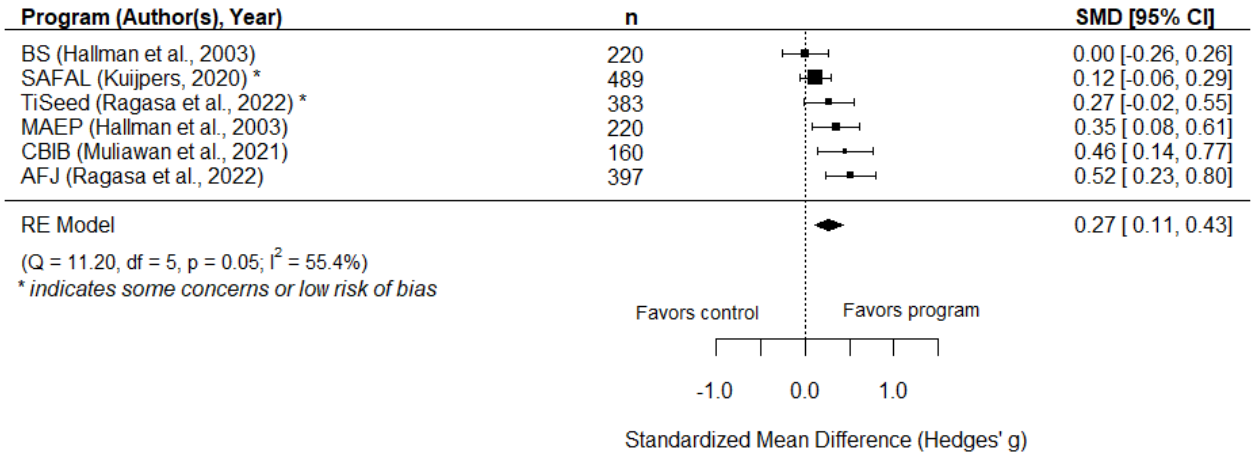
The moderator analyses for total expenditure indicated that aquaculture interventions that provided training ($\hat{\beta}$ = 0.42, p < .001) and credit ($\hat{\beta}$ = 0.27, p = .03) showed larger effects compared to other program components, whereas interventions that included post-production activities were associated with smaller effects ($\hat{\beta}$ = -0.29, p = .01) compared to those providing other components along the aquaculture value chain.

The moderator analyses for food expenditure indicated that longer follow up periods are associated with smaller effects compared to estimates captured closer to the end of the intervention delivery ($\hat{\beta}$ = -0.07, p < .001).

Profit

We initially included five studies reporting on seven programs for this analysis and found a non-statistically significant effect on profit measures ($\widehat{SMD}$ = 0.01, 95% CI [-0.39 to 0.4], p = .97). However, after excluding one influential outlier (Rachmawati, Kusnadi, and Tinaprilla 2023), we found that aquaculture programs led to a moderate increase in profit ($\widehat{SMD}$ = 0.27, 95% CI [0.11 to 0.43], p < .001; Figure 7 and Appendix 20), showing moderate heterogeneity (I^2 = 55.38%). The moderator analyses results indicated that programs in Bangladesh and those that targeted communities showed smaller effects ($\hat{\beta}$ = -0.26, p = 0.03) compared to programs in other countries and those that targeted individuals. However, these two moderator variables are colinear, so identifying the main characteristic driving the change is challenging.

Figure 7: Forest plot of meta-analysis on profit

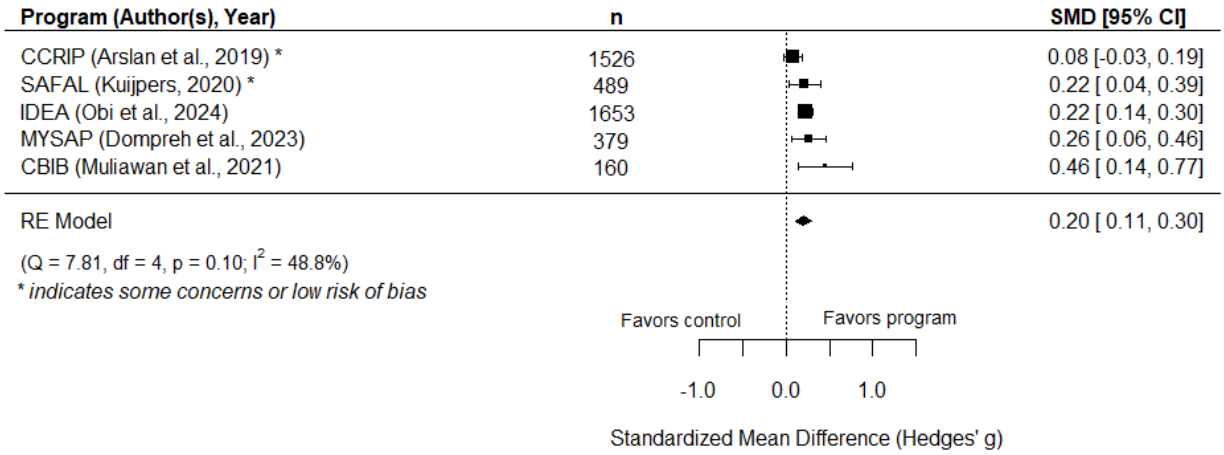


Revenues

For this analysis, we initially included six programs and did not find a statistically significant effect on revenues ($\widehat{SMD}$ = 0.07, 95% CI [-0.14 to 0.5], p = .97). As with profit, after excluding an influential outlier (Rachmawati, Kusnadi, and Tinaprilla 2023), we found that aquaculture interventions also brought a moderate increase in revenues ($\widehat{SMD}$ = 0.20, 95% CI [0.11 to 0.30],

p < .001; Figure 8 and Appendix 20). This effect showed moderate heterogeneity (I^2 = 48.78%) and the sensitivity analyses confirmed the result. We found no statistically significant moderators for this outcome.

Figure 8: Forest plot of meta-analysis on revenues



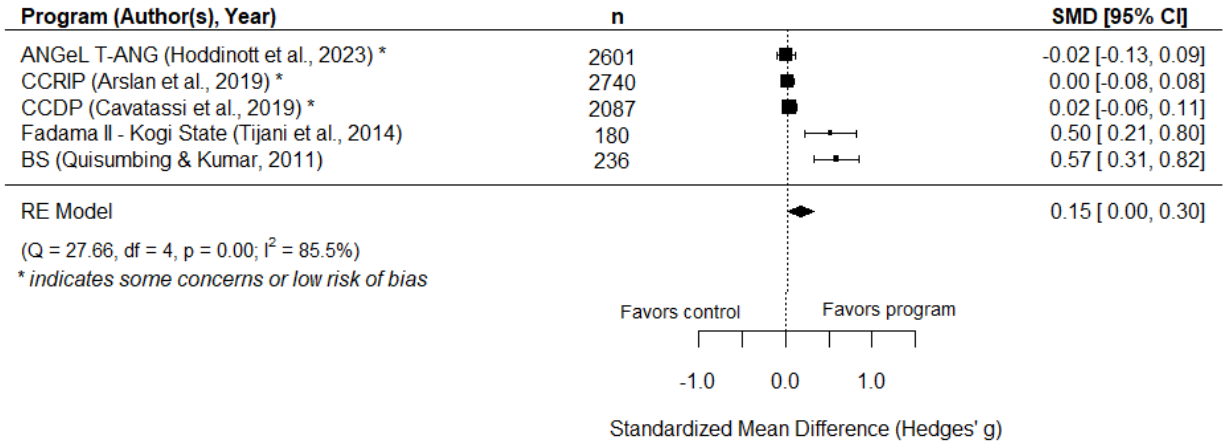
Assets

We explored assets through three measures. First, given the diversity of measures reported across studies, we ran an RVE model for an aggregated measure of assets. Reported measures included, for example: area of cultivated land, household durable asset index, household fishing assets index, value of non-livestock assets, value of agricultural assets, value of productive assets, value of jewelry, total value of assets, and wealth index. We included 82 estimates derived from seven studies reporting on eight programs. We found that aquaculture programs did not significantly affect this aggregated measure of assets ($\widehat{SMD}$ = 0.13, 95% CI [-0.08 to 0.34], *p* = .18), and showed substantial heterogeneity (I^2 = 87.40%). We did not detect publication bias, nor did we identify statistically significant moderators for this outcome.

Second, we explored measures of land area as a proxy for assets, for which we included one study reporting on two programs. However, we found no statistically significant effects of aquaculture programs on this outcome ($\widehat{SMD}$ = -0.08, 95% CI [-0.33 to 0.16], *p* = .49; Appendix 20). There was insufficient evidence to perform moderator analyses and publication bias tests for this outcome.

Third, we analyzed productive assets, including, for example, fishing or agricultural assets. We originally included five studies reporting on six programs in this analysis and found a non-statistically significant effect on this outcome, ($\widehat{SMD}$ = 0.07, 95% CI [-0.09 to 0.24], *p* = .39). However, we tested two outliers separately, both derived from Quisumbing and Kumar (2011). After excluding the estimate from MAEP, we found that aquaculture interventions led to a small but significant increase in productive assets ($\widehat{SMD}$ = 0.15, 95% CI [0.002 to 0.30], *p* = .05; Figure 9), which showed substantial heterogeneity (I^2 = 85.54%). While the sensitivity analyses corroborated this finding, we did not detect significant moderators for this outcome.

Figure 9: Forest plot of meta-analysis on productive assets



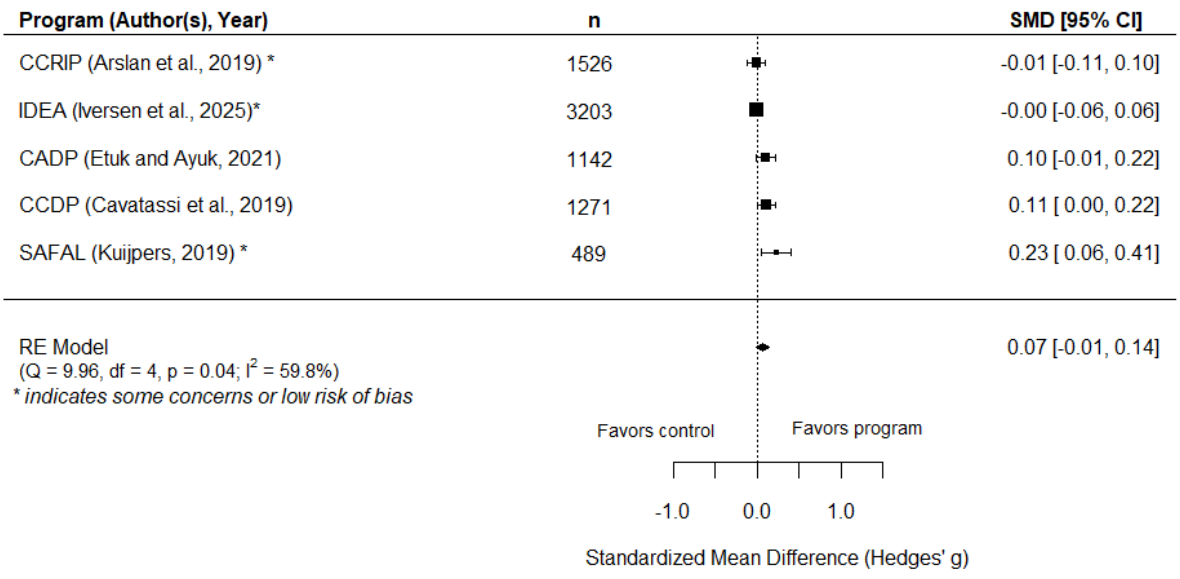
Poverty headcount ratio

We included five programs in the analysis of poverty headcount, which measures the population ratio under a national poverty line. We did not find a statistically significant effect on this outcome ($\widehat{SMD}$ = 0.05, 95% CI [-0.09 to 0.18], p = .49; Appendix 20), which showed substantial heterogeneity (I² = 86.19%). We did not find statistically significant moderators for this outcome.

Market participation

For this analysis we included five programs, which reported measures on the value, quantity or share of aquaculture products sold. We found that aquaculture programs did not significantly affect market participation ($\widehat{SMD}$ = 0.07, 95% CI [-0.01 to 0.14], p = .08; Figure 10), showing moderate heterogeneity (I^2 = 59.83%). While the sensitivity analyses corroborated this finding, the moderator analyses indicated that interventions that provided credit showed larger effects ($\hat{\beta}$ = 0.13, p < .01) compared to programs with other activities along the value chain, though with such a small number of included studies, these analyses are exploratory.

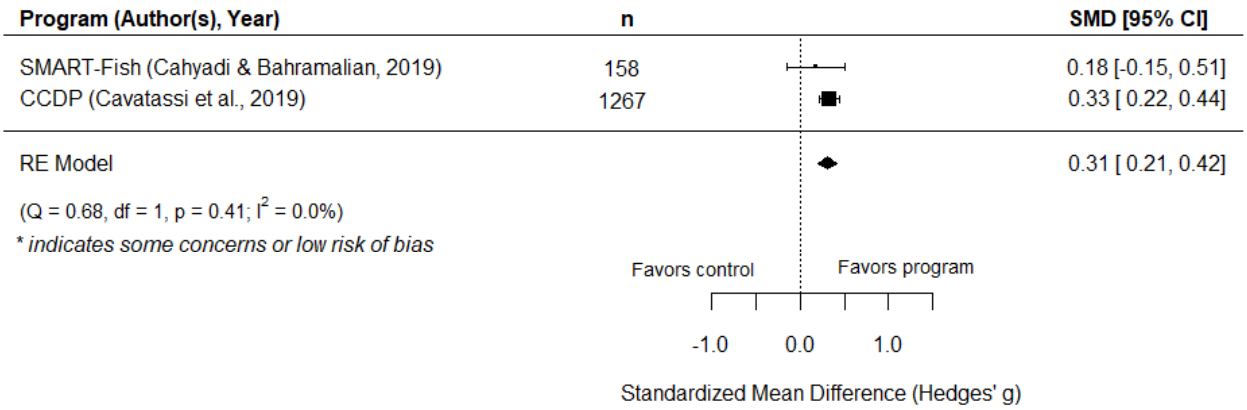
Figure 10: Forest plot of meta-analysis on market participation



Price received

We included two programs in the analysis of prices received from aquaculture produce. We found that aquaculture interventions led to a moderate increase in price received ($\widehat{SMD}$ = 0.31, 95% CI [0.21 to 0.42], p < 0.001; Figure 11). There was insufficient evidence to conduct moderator analyses or publication bias tests for this outcome.

Figure 11: Forest plot of meta-analysis on price received



3. Nutrition and food security

We analyzed several measures of food security, including an aggregated measure of food security, the Food Consumption Score (FCS), the Household Dietary Diversity Score (HDDS), the Food Insecurity Experience Scale (FIES), and the Household Food Insecurity Access (HFIAS). We only found that aquaculture programs led to a small but significant increase in the FCS. Likewise, we did not find statistically significant effects on different measures of fish consumption, women's body mass index, or children's malnutrition measures.

Food security

We explored food security through different measures. We first used an RVE model to explore this outcome, given the variety of measures reported on food security. Examples of reported measures include per capita caloric intake, Food Consumption Score (FCS), Food Insecurity Experience Scale (FIES), Global Dietary Quality Score (GDQS), households experiencing food crisis, number of people unable to eat healthy food, and Months of Adequate Household Food Provisioning (MAHFP). We included 86 estimates derived from 13 studies reporting on six programs. We did not find a statistically significant effect on this aggregated measure of food security ($\widehat{SMD}$ = 0.06, 95% CI [-0.17 to 0.30], p = .57), which showed considerable heterogeneity (I^2 = 94.79%). The moderator analyses indicated that interventions implemented in countries with very high exposure to climate shocks showed smaller effects than those implemented in countries with lower exposure ($\hat{\beta}$ = -1.28, p < .01).

In addition, we examined established measures of food security, including the Food Consumption Score (FCS), Household Dietary Diversity Score (HDDS), Food Insecurity Experience Scale (FIES), and Household Food Insecurity Access Scale (HFIAS). We only found that aquaculture programs led to a small but significant increase in the FCS ($\widehat{SMD}$ = 0.14, 95% CI [0.06 to 0.22], p < .001; Appendix 20), which was based on four programs. While we corroborated this result with the sensitivity analyses, we could not conduct moderator analyses for this outcome.

We included six programs in the analysis of HDDS and found a non-statistically significant effect ($\widehat{SMD}$ = -0.08, 95% CI [-0.30 to 0.14], *p* = .48; Appendix 20). The moderator analyses revealed that aquaculture interventions that provided training sessions showed larger effects ($\hat{\beta}$ = 0.45, *p* = .03) than programs with other components along the value chain. Moreover, interventions implemented in lower-middle income countries showed larger effects ($\hat{\beta}$ = 0.46, *p* = .03) compared to lower income countries, and the longer the timespan covered by the evaluation the larger the effect ($\hat{\beta}$ = 0.08, *p* = .02).

In turn, we found that aquaculture programs reduced FIES ($\widehat{SMD}$ = -0.05, 95% CI [-0.41 to 0.31], *p* = .78; Appendix 20) and HFIAS ($\widehat{SMD}$ = -0.44, 95% CI [-1.35 to 0.47], *p* = .34; Appendix 20), but these reductions were not statistically significant and were only based on two programs each. We were unable to conduct moderator analyses for these outcomes.

Fish consumption

We explored this outcome through three measures but did not find statistically significant effects on any of the measures. First, we ran an RVE model for an aggregated measure of fish consumption given the heterogeneity of measures used for measuring this outcome. Examples of the measures reported include average share of fish used for home consumption, fish consumption frequency (number of days a month), total meals with fish per month, value of fish consumption per capita, and weight of fish consumption per week/month/year. We included 37 estimates derived from eight studies reporting on seven programs and did not find a significant effect on this aggregated measure of fish consumption ($\widehat{SMD}$ = 0.10, 95% CI [-0.11 to 0.31], *p* = .30, I^2 = 97.06%). The moderator analyses revealed that aquaculture programs that provided training ($\hat{\beta}$ = -0.28, *p* = .04) or post-production support ($\hat{\beta}$ = -0.32, *p* = .04) showed smaller effects compared to interventions that focused on other stages of the value chain. Moreover, effects tended to become smaller with evaluations further away from the end of the program ($\hat{\beta}$ = -0.04, *p* = .02). Estimates from evaluations published in peer-review journals showed larger effects ($\hat{\beta}$ = 0.39, *p* = .03) compared to estimates from grey literature reports.

We also explored two specific measures for this outcome: weight and frequency of fish consumed. For the analysis of the weight of fish consumed, we included six programs and found a non-significant effect ($\widehat{SMD}$ = 0.10, 95% CI [-0.06 to 0.25], *p* = .21; Appendix 20). The moderator analyses indicated that the larger the program size, the smaller the effect, although this is negligible ($\hat{\beta}$ < -0.001, *p* < .01). Likewise, programs that did not focus uniquely on aquaculture showed smaller effects ($\hat{\beta}$ = -0.37, *p* < .01) compared to aquaculture-tailored programs, and estimates from peer-reviewed articles showed larger effects ($\hat{\beta}$ = 0.34, *p* = .01) compared to those from grey literature studies.

In turn, we included three programs in the analysis of fish consumption frequency and did not find a significant effect ($\widehat{SMD}$ = -0.05, 95% CI [-0.47 to 0.37], *p* = .83; Appendix 20). There was insufficient evidence to run moderator analyses and publication bias tests for this outcome.

Women's Body Mass Index (BMI)

We included three studies reporting on four programs in this analysis. We did not find a statistically significant effect of aquaculture programs on women's BMI ($\widehat{SMD}$ = 0.05, 95% CI [-0.02 to 0.13], *p* = .16; Appendix 20). We did not detect any heterogeneity (I^2 = 0%). The sensitivity analyses corroborated this result; however, we did not identify statistically significant moderators for this outcome.

Children's malnutrition

We explored three measures of children's malnutrition: stunting (height-for-age, HAZ), underweight (weight-for-age, WAZ), and wasting (weight-for-height, WHZ). Three of the four programs that reported these measures included a nutrition education activity, however, we did not find statistically significant effects on any of these outcomes.

For the analysis of children's stunting, we included three studies reporting on four programs and found a non-significant effect ($\widehat{SMD}$ = 0.01, 95% CI [-0.10 to 0.11], *p* = .88; Appendix 20). We did not detect any heterogeneity (I^2 = 0%). The sensitivity analyses corroborated this result, but we did not identify statistically significant moderators for this outcome.

We included the same two programs in the analysis of children's underweight ($\widehat{SMD}$ = -0.03, 95% CI [-0.16 to 0.10], *p* = .64; Appendix 20) and wasting ($\widehat{SMD}$ = -0.04, 95% CI [-0.17 to 0.09], *p* = .51; Appendix 20) but none were statistically significant. For both outcomes, we again did not identify any heterogeneity (I^2 = 0%) and could not conduct moderator analyses or publication bias tests.

4. Women's empowerment

Our analyses indicate that aquaculture interventions significantly increased established women's empowerment indices (WEAI and WEI); however, we did not find statistically significant effects on the aggregated women's empowerment measure or any of the three individual proxies to women's empowerment (decision-making, mobility, and economic empowerment).

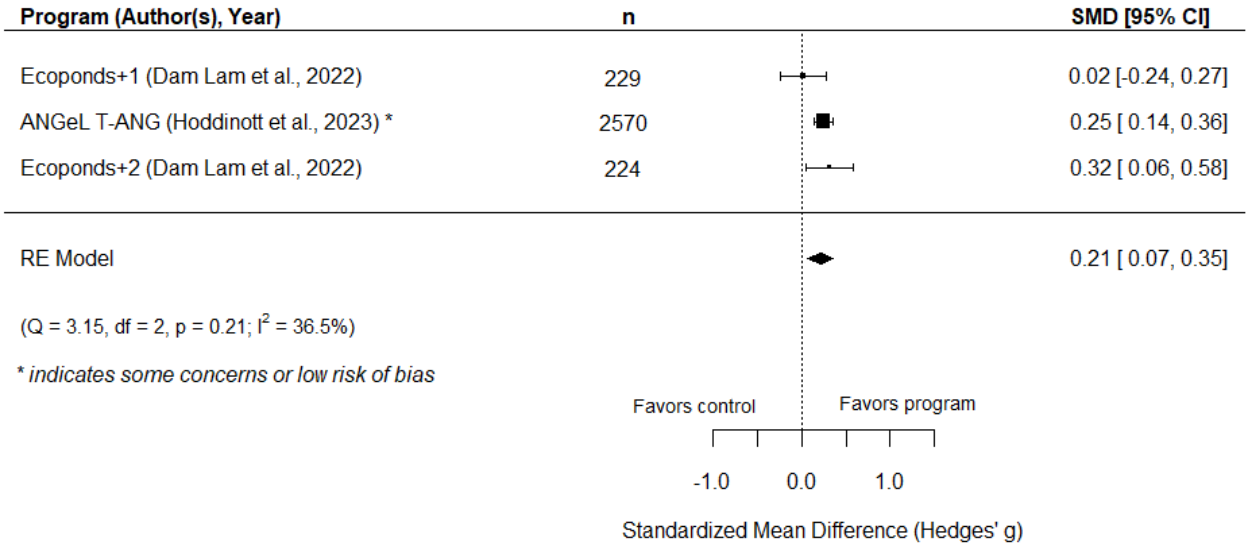
Women's empowerment (aggregated measure)

Included studies reported a range of measures on women's empowerment, including indices (e.g., Abbreviated Women's Empowerment in Agriculture Index - A-WEAI) and measures of specific empowerment aspects (e.g., ability to attend meetings, visit individuals or travel; ability to take owns decisions within household; contribution to household income). Hence, we used an RVE model to explore an aggregated measure of this outcome. We included 192 estimates derived from 12 studies reporting on 10 programs. We did not find a significant effect on this aggregated measure of women's empowerment ($\widehat{SMD}$ = 0.12, 95% CI [-0.001 to 0.24], *p* = .052), which showed substantial heterogeneity (I^2 = 88.10%). We did not identify statistically significant moderators for this outcome.

4.2. Women's Empowerment in Agriculture Index (WEAI)

We included two studies reporting on three programs (or treatment arms) in this analysis. We found that aquaculture programs significantly increased WEAI scores ($\widehat{SMD}$ = 0.21, 95% CI [0.07 to 0.35], *p* = .004; Figure 12), which did not show an important level of heterogeneity (I^2 = 36.49%). We corroborated this result with the sensitivity analyses, but there was insufficient evidence to conduct moderator analyses and publication bias tests for this outcome.

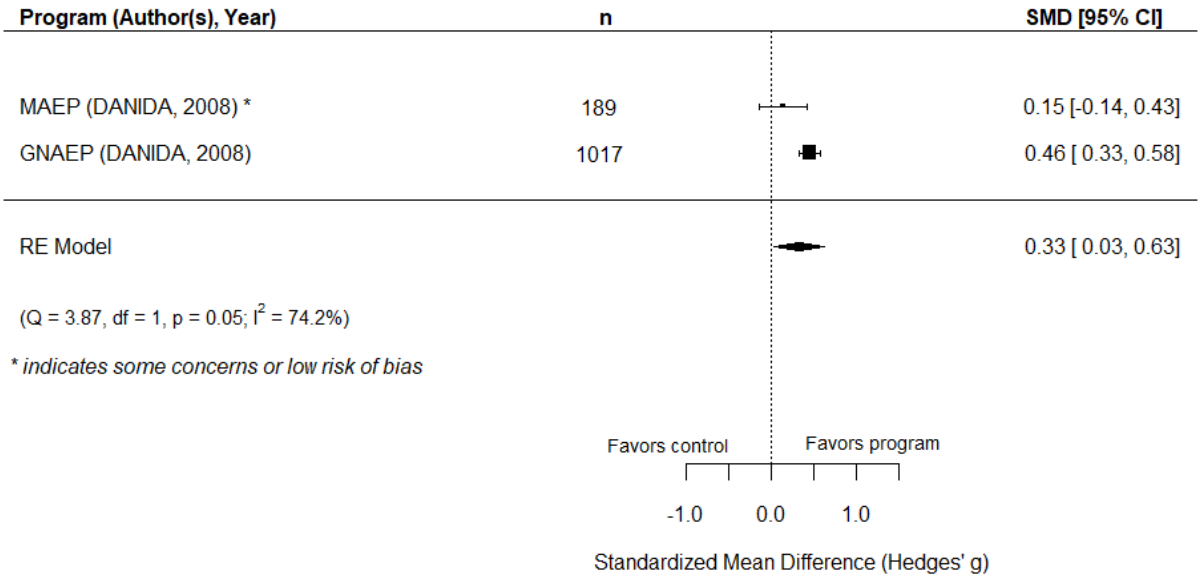
Figure 12: Forest plot of meta-analysis on WEAI



4.3. Women's Empowerment Index (WEI)

We included two estimates from two programs in this analysis. We found that aquaculture interventions significantly increased WEI scores ($\widehat{SMD}$ = 0.33, 95% CI [0.03 to 0.63], *p* = .003; Figure 13). The observed effects showed substantial heterogeneity (I^2 = 74.17%); however, we could not carry out moderator analyses and publication bias tests due to insufficient data.

Figure 13: Forest plot of meta-analysis on WEI



4.4. Women's decision-making

We originally included six programs in this analysis. We found a non-statistically significant effect ($\widehat{SMD}$ = 0.11, 95% CI [-0.03 to 0.25], *p* = .13). After removing one outlier (Cavatassi et al. 2019), we found a smaller but still non-significant effect ($\widehat{SMD}$ = 0.03, 95% CI [-0.07 to 0.13], *p*

= .60; Appendix 20). The moderator analyses revealed that evaluations that used pipelines to create a comparison group showed larger effects compared to evaluations that used the absence of the intervention as a counterfactual ($\hat{\beta}$ = 0.24, *p* = .03). In contrast, programs that focused on post-production showed smaller effects compared to interventions that provided other components along the value chain ($\hat{\beta}$ = -0.24, *p* = .03). However, these two moderators are colinear, so we cannot identify the main characteristic driving the change.

4.5. Women's mobility

For this analysis, we included three studies reporting on four programs. We did not find a statistically significant effect ($\widehat{SMD}$ = 0.10, 95% CI [-0.11 to 0.31], *p* = .33; Appendix 20). The moderator analyses revealed that the longer the timespan covered by the evaluation, the larger the effect on women's mobility ($\hat{\beta}$ = 0.03, *p* < .001).

4.6. Women's economic empowerment

We included three studies reporting on four programs in this analysis. We found a non-statistically significant effect on economic empowerment, which incorporates income and assets measures ($\widehat{SMD}$ = 0.09, 95% CI [-0.19 to 0.36], *p* = .54; Appendix 20).

The moderator analyses revealed that the longer the timespan covered by the evaluation the larger the effect ($\hat{\beta}$ = 0.21, *p* < .001). In addition, the following moderators were statistically significant although these are colinear, which hinders the identification of the main characteristic(s) driving the change: interventions the implemented post-production activities, those with components beyond the aquaculture sector, those implemented in lower-middle income countries, and estimates from peer-reviewed articles showed larger effects compared to interventions focused on other components along the value chain, programs focused only on aquaculture, those in lower-income countries, and estimates from grey literature studies ($\hat{\beta}$ = 0.47, *p* = .001). In contrast, interventions that provided technical assistance, credit, or technology to participants, and estimates that required assumptions to calculate an effect size showed smaller effects compared to programs that provided other components along the value chain and to estimates from studies that reported all required information ($\hat{\beta}$ = -0.47, *p* = .001).

Qualitative synthesis

We synthesized qualitative evidence to identify factors that influence the successful implementation of aquaculture programs to improve nutrition, dietary diversity, or food security. Based on a separate search for qualitative evidence, we draw from 33 studies that used primary data to explore pathways between aquaculture programs and nutrition.

Description of qualitative evidence identified

We initially identified 41 relevant studies, of which eight were qualitative, 14 were descriptive quantitative, and 19 were mixed-methods studies. We rated almost half of the studies as high (n = 2) or moderate quality (n = 18). Of the remaining studies, we rated 13 studies as low quality and eight studies as critical quality. These eight studies were excluded from the synthesis; hence, we extracted data and conducted analyses based on the remaining 33 studies. These studies covered 30 programs in eight countries, but half of these programs were implemented in Bangladesh. Appendix 21 presents the disaggregated critical appraisal ratings and details about the geographic distribution, intervention components, and outcomes assessed by these studies.

Findings from the qualitative evidence

Based on the conceptual framework defined for this analysis, we organized our data into themes relevant to determinants of nutrition in the theorized pathway from participating in an aquaculture program to improving nutritional status. We only report themes drawing from more than a single program. We identified themes related to enabling and underlying determinants of nutrition, but none for immediate determinants (Table 5). When describing each theme, we present illustrative examples, while further examples are included in Appendix 21.

Table 5. Summary of evidence synthesis results

Type	Determinant	Themes	# of programs/studies, countries, and critical appraisal rates
Immediate determinants of nutrition	Consumption and dietary intake	We did not find themes for this determinant.	
	Health status and disease exposure	We did not find themes for this determinant.	
Underlying determinants of nutrition	Household food security	Improved production	• 11 programs (# studies = 11) • Bangladesh, India, Malawi • Moderate = 6, Moderate & Low = 2, Low = 3
		Fish availability and affordability	• 8 programs (# studies = 8) • Bangladesh, Ghana, India, Malawi • Moderate = 5, Moderate & Low = 2, Low = 1
		Improved income	• 3 programs (# studies = 3) • Bangladesh, Myanmar • High = 1, Moderate = 1, Low = 1
		Market prices and motivation to sell fish	• 3 programs (# studies = 3) • Bangladesh and Malawi • Moderate = 3
		Seasonal weather patterns	• 3 programs (# studies = 3) • Bangladesh, Ghana, Malawi • Moderate = 1, Moderate & Low = 2
		Water salinity	• 2 programs (# studies = 2) • Bangladesh • Moderate = 2
	Household or caregiver practices and preferences	Preferences or taste for serving fish	• 6 programs (# studies = 6) • Bangladesh, India, Malawi • Moderate = 5, Moderate & Low = 1
		Receptiveness to changing cooking practices	• 3 programs (# studies = 3) • Bangladesh, Malawi • Moderate = 2, Low = 1
	Women's participation in aquaculture	Improved decision-making for consumption	• 3 programs (# studies = 3) • Bangladesh • Moderate = 2, Low = 1
	Availability of services and	Nutrition knowledge as a	• 3 programs (# studies = 3) • Bangladesh • Moderate = 1, Moderate & Low = 1, Low = 1

Type	Determinant	Themes	# of programs/studies, countries, and critical appraisal rates
	nutrition information	factor for fish consumption	
		Nutrition information dissemination	• 2 programs (# studies = 2) • Bangladesh, Nigeria • Moderate = 2
Enabling determinants of nutrition	Resources	Assets for food consumption and security	• 12 programs (# studies = 12) • Bangladesh, India, Kenya, Malawi, Myanmar • High = 2, Moderate = 6, Moderate & Low = 1, Low = 3
		Accessibility to markets to buy food	• 4 programs (# studies = 5) • Bangladesh, Myanmar • High = 1, Moderate = 2, Low = 2
	Gender norms	Harmful norms, limited childcare and unequal treatment	• 10 programs (# studies = 11) • Bangladesh, Ghana, India, Malawi • Moderate = 8, Moderate & Low = 1, Low = 2
		Women's perception of improving status or other benefits from aquaculture	• 7 programs (# studies = 8) • Bangladesh and Cambodia • Moderate = 7, Low = 1
	Governance	We did not find themes for this determinant.	

Immediate determinants of nutrition

We identified no themes for consumption and dietary intake, or health status or disease exposure, which are immediate conditions that affect nutritional status. However, some studies of aquaculture programs measured dietary diversity using indicators such as Minimum Dietary Diversity (Hossain et al. 2024; Thorne-Lyman et al. 2017), a measure of the number of food groups consumed as a proxy for adequacy of micronutrient intake. Instead, we found that studies explored pathways from aquaculture participation to availability of food, which we discuss in the section on underlying determinants of nutrition.

Underlying determinants of nutrition

We identified themes related to four underlying determinants. First, we identified six themes related to household food security, which refers to the extent to which fish and other food are consistently available and accessible. The themes cover how increased food security can be connected to (i) improved production, (ii) fish availability and affordability, and (iii) improved income, (iv) market prices for selling produced fish, (v) seasonal weather patterns affecting fish availability and prices, and (vi) water salinity. Second, we observed two themes related to household or caregiver practices and preferences (which include, for example, preparing meals for children and members of the household): preferences or taste for serving fish, and receptiveness to changing cooking practices. Third, we found that women participating in aquaculture programs experienced improved decision-making roles relevant to consumption. And fourth, we identified two themes around the availability of services and nutrition information: gaining nutrition knowledge as a factor for fish consumption, and participants' willingness to continue information dissemination toward broader nutrition-related social and behavior change.

1. Household food security

Eleven programs in Bangladesh, India and Malawi reported on **improved production as a factor for enhanced food security.** Participants' own production of fish or other crops made food more readily available or precluded the need to buy these items. For example, participants in programs in Bangladesh reported that being able to produce mola and carp in their own ponds or adopting an integrated floating cage aquageoponics system allowed participants to have more fish available for their own consumption (USAID 2023; Haque et al. 2015). A study of a program in Malawi credited improved productivity, including harvesting cycles, fish size, and quality, to farmer households increasing their consumption of fish (Mubaya et al. 2023).

Eight programs in Bangladesh, Ghana, India, and Malawi noted how **variations in availability and affordability of fish affected purchasing and consumption decisions**. For instance, a program in India provided dried fish powder to Anganwadi or rural childcare centers, but centers were less inclined to continue using it after the program, as staff identified eggs as a cheaper source of protein (Rinck and Kundu 2023). In a baseline study to inform programs aimed at promoting women's participation in the aquaculture post-harvest sector, respondents in Ghana and Malawi reported that high prices for fish were a barrier to buying fish for consumption (Kadongola and Ahern 2023).

Three programs in Bangladesh and Myanmar reported that **improved income is a factor in boosting food security**. For example, one study in Bangladesh suggested that providing training helped credit borrowers increase their income and expenditures on food (Mahmud et al. 2022). A program in Myanmar that helped participants adopt fish polyculture was associated with helping them earn additional income through the production of crops and fish, which was spent to buy food and improve food security (Wang et al. 2024).

Market prices or motivation to sell produced fish can present trade-offs for whether to keep fish for consumption. This trade-off was noted in three programs in Bangladesh and Myanmar. For example, a program in Myanmar focused on practicing rohu-Indian major carp polyculture. While farmers in one region opted to retain some of the fish for direct consumption, farmers from another region sold all the fish they produced. Authors noted that rohu was popular among consumers due to its taste and affordability, which improved marketability and may have factored into farmers' decisions to sell (Karim et al. 2020). Likewise, in a program in Bangladesh, most farmers reported keeping the fish they produced to consume at home, but selling the shrimp they produced. Though the prices for fish and shrimp fluctuated, and in some cases, farmers could earn a higher price for fish, farmers primarily produced shrimp to generate income (Kruijssen et al. 2019).

Three programs in Bangladesh, Ghana, and Malawi reported on how **seasonal weather patterns can affect the availability of food and fish prices for consumers**. For instance, respondents in Malawi reported that bad weather, such as wind, rain, storms, and heat waves, made fish scarce and difficult to buy in June-July (Kadongola and Ahern 2023). A study in Bangladesh found that more and diverse fish species were available during the peak fishing season from July to November, and low prices, among other factors, contributed to higher consumption at that time (Akter et al. 2019).

Finally, two programs in Bangladesh reported **high water salinity as a barrier to drinking water**. While participants in areas with high water salinity reported shortages of drinking water (USAID 2023), low salinity can contribute to more readily available and cheaper drinking water (Kabir et al. 2020).

2. Household or caregiver practices and preferences

Six programs in Bangladesh, India and Malawi reported that the **preferences of caregivers and children affected whether they served fish or fish products to children**. Studies reported that, despite receiving nutrition education through aquaculture programs, mothers and caregivers were reluctant to feed fish or certain fish to infants and young children. This reluctance was associated with a fear of bones, the amount of time required to prepare fish (e.g., remove bones, mash fish into paste), and concerns about teeth development, which discouraged feeding micronutrient-rich small indigenous fish to children in Bangladesh (Thorne-Lyman et al. 2017) and catfish to infants and young children in Malawi (Ahern et al. 2020). In addition, caregivers had noted instances where children did not want to eat fish or fish products. In India children had strongly rejected the dried fish powder provided by the program (Rinck and Kundu 2023), while in Bangladesh, children generally did not like small fish or preferred fish with fewer bones (USAID 2023).

However, three studies also reported instances where participants were receptive to fish or fish products promoted by the program. In a program in Malawi, which supported production and processing of nutrient-rich foods, participants reported that infants were very receptive to eating local dishes with added fish powder. They favorably rated taste, odor or texture based on infants' happy facial expressions and finishing a serving (Ahern et al. 2020). Two studies in Bangladesh associated participating in aquaculture training and nutrition education with serving more small indigenous fish (mola carplet) to children, as participants gained awareness of nutritional benefits, affordability and availability from their own production, and cultural acceptance (Akter et al. 2019; 3ie et al. 2025).

The second theme related to practices draw from three programs. These reported that **receptiveness to changing cooking practices can affect whether households ultimately improve consumption**. For example, participants in a program in Malawi enjoyed experimenting with adding nutrient-rich powders to local recipes or adapting household dishes to improve infant and young child feeding. They also made better use of their time and reduced the need to prepare separate dishes. The authors concluded that collaborating with participants to develop recipes and cooking demonstrations helped to make dishes culturally acceptable (Ahern et al. 2020). However, in Bangladesh, women farmers reported that though they were aware of the importance of cooking with more vegetables through the program, it was difficult to change cooking habits, and they preferred to maintain their usual way of cooking (Orbicon/NCG 2019). The program promoted improved practices in vegetable, aquaculture and other farming and provided information on food preparation for balanced nutrition, though it did not include cooking demonstrations.

3. Women's participation in aquaculture

Three programs in Bangladesh reported that **women participating in aquaculture programs experienced improved decision-making roles relevant to consumption**. Only one of these programs included activities focused on women's empowerment: a program that provided training for women-led small-scale fish production. Participants reported that earnings from selling fish produced through the program could be used for food expenditures without challenges from their spouses (Dam Lam et al. 2022). A farmer field school program provided training for homestead aquaculture and other forms of agriculture, along with nutrition education, and women reported contributing more to household food security and nutrition by gaining knowledge through the program (DANIDA 2011). For another program that provided feed and training about aquaculture, horticulture, and nutrition, women reported improving their

children's consumption because they had gained a stronger role in household spending decisions due to participating in the program (Hargreaves, Abul, and Islam 2017).

4. Availability of services and nutrition information

Three programs in Bangladesh reported that **gaining knowledge about nutrition from an aquaculture program could be a factor in improving fish consumption**. Studies reported gaining knowledge as complementary to enhancing production toward the goal of improved consumption. Participants of one program that provided aquaculture inputs and training reported gaining awareness of the nutritional value of consuming whole fish, including the head and bones. Their nutrition awareness and improved productivity were associated with participants increasing fish consumption, including nutrient-rich small indigenous fish (Hargreaves, Abul, and Islam 2017). Similarly, another study credited participants' increased fish consumption to receiving nutrition education on the importance of consuming small indigenous fish, in conjunction with making fish more available by practicing pond aquaculture (Akter et al. 2019).

Two programs in Bangladesh and Nigeria reported on **participants' willingness to promote information dissemination about nutrition, which can affect goals to expand social and behavior change communication**. In Bangladesh, a program engaged in an information campaign with suppliers with the aim that they would, in turn, promote the consumption of mola fish, vegetables, carp-mola polyculture and pond dike cropping with customers. However, most suppliers did not disseminate nutrition messages due to low feasibility, such as a lack of time to convey messages when serving multiple customers at once. Authors noted a need to collaborate with government agencies to identify appropriate platforms to promote nutrition-sensitive aquaculture (USAID 2023). A program in Nigeria collaborated with women and youth fish processors to reinforce and help disseminate information about nutrition and food safety. The program developed tools adapted to local literacy levels and printed nutrition and food safety information on hand fans, wrist bands, and aprons. Most participants reported that the tools helped them talk with customers about the benefits of fish consumption (Adegoye 2022).

Enabling determinants of nutrition

While we did not identify themes relevant to governance, we identified themes for the two other enabling determinants of nutrition, resources and gender norms. Enabling determinants are shaped by broader sociocultural or economic contexts but have implications for households and individuals. Themes related to resources include household assets for food consumption and security, and market accessibility to buy food. Themes related to norms include (i) how cultural and religious norms, lack of childcare alternatives, and unequal treatment compared to men can discourage women's participation in aquaculture, and (ii) how participating in aquaculture activities can empower women by earning an income, gaining decision-making power, or improving their status. While these gender norm themes are not immediately linked to nutritional status or food security, they exemplify how disabling contexts can prevent aquaculture programs from realizing their potential for affecting nutrition-related outcomes.

1. Resources

Studies from 12 programs in Bangladesh, India, Kenya, Malawi, and Myanmar reported on how **household assets can be associated with food security or consuming fish** or other nutrient-rich food. Six studies in Bangladesh, Kenya and Myanmar suggested that more or better household assets (e.g., pond/land ownership, closer proximity to ponds, better quality ponds, and access to credit or better credit terms) contributed to better food consumption or higher expenditure. For instance, a study in Bangladesh reported that an increase in the value

of household assets was associated with an increase in the likelihood of higher food expenditure (Mahmud et al. 2022). A study in Myanmar reported that access to credit or off-farm income among aquaculture farmers was associated with improved food security (Nway et al. 2021). In contrast, two studies reported how having fewer or lower quality assets could be a factor for optimizing resources toward food consumption and security. For example, a study reported that women in Bangladeshi households with less desirable ponds (i.e., highly shaded) may have been more motivated to adopt integrated floating cage aquageoponics system technology to maximize production, compared to households with better ponds (Haque et al. 2015).

In addition, programs in India, Malawi, Myanmar, and Nigeria reported that participants' access to post-harvest technologies was a means to improve food security. For example, although a program in Malawi helped participants increase fish production, a lack of refrigeration to store fish that could not be consumed immediately was a barrier to improving food security (Mubaya et al. 2023). Another study explored experiences with portable fish driers in Myanmar, where participants reported that increasing the supply and shelf-life of dried fish available for home consumption was considered a factor for improved food security during times of food scarcity over the year (Nway et al. 2021).

The second theme related to resources was identified in studies from four programs in Bangladesh and Myanmar. These studies indicated that a **lack of access to local markets can affect participants' ability to buy food**. For example, a large distance from local markets was reported as a barrier to food security for program participants in Bangladesh (Mahmud et al. 2022) and Myanmar (Wang et al. 2024).

2. Gender norms

Studies from ten programs in Bangladesh, Ghana, India, and Malawi described how **harmful norms, limited alternative childcare options, and unequal treatment can reduce women's ability and willingness to participate in aquaculture programs**. These represent a first hurdle for women to benefit equitably from aquaculture interventions.

Cultural and religious norms, from requiring permission to travel to unsafe surroundings, can demotivate women from fully participating in aquaculture activities. For example, in India, women participating in a program with a collective fishpond near a temple could not consistently access the pond due to religious restrictions against women approaching the area during menstruation (Hudson et al. 2019). A study in Bangladesh reported that women who became Female Farmer Trainers were motivated by the opportunity to expand their mobility and social connections; however, very few expressed interest in the role because of the challenge to balance household responsibilities with the need to participate in training sessions for 5-6 hours per day (DANIDA 2011).

Care responsibilities can also make it difficult for some women to participate in aquaculture programs, particularly if the lack of alternative options clashes with program participants or staff. For instance, studies from programs in Bangladesh reported women receiving complaints when bringing their children to program activities, as they disrupted the sessions (DANIDA 2011; USAID 2023).

Studies also reported on inequalities women faced while participating in aquaculture programs. A program in Bangladesh intended to ensure that women and men accessed credit; however, it found that, on average, men received loans over seven times higher women (USAID 2023).

Female participants of another program in Bangladesh noted a lack of specific project messaging regarding men's roles in nutrition-related tasks (3ie et al. 2025). Moreover, there are instances where unequal behaviors stem from within program participants. For example, in a program in Bangladesh, male fish farmers hesitated to seek advice from female local service providers, which affected the female providers' ability to support with technical assistance (Kruijssen et al. 2019). Another program in Bangladesh trained both women and men to serve as program facilitators, but very few women passed the exam, while no men had failed. Women expressed concern that they were not being treated as capable (Orbicon/NCG 2019).

The second theme related to gender norms drew from seven programs in Bangladesh and Cambodia. These studies reported that **women perceived benefits from practicing aquaculture that could help challenge the status quo, such as acquiring skills, status or decision-making power**. For example, women participating in a program in Cambodia felt they could challenge existing gender roles and beliefs, including feeling able to discuss business matters and assert opinions, because of earning an income from practicing aquaculture (Hillenbrand et al. 2014). Likewise, women owners of micro franchises in Bangladesh also valued earning an income, gaining independence, and contributing to the household by participating in aquaculture. This was reflected, for instance, in not needing to ask their parents for money or covering their education costs, and women recognizing that by earning their own income, they could opt to spend it on their children's education without needing to ask their spouses (USAID 2023).

Synthesis of cost evidence

We synthesized the evidence related to review question 5, focused on the cost-effectiveness of included programs. This section outlines the overall results from the cost evidence analysis and summarizes the three projects where we found relevant and reliable data.

We identified cost information for 23 projects, obtained from 101 distinct information sources. Most sources reported project budgets (n = 55), while a smaller number also offered different types of cost information (n = 17). However, only a limited number conducted thorough economic evaluations, as most cost analyses were merely basic budget reports or cost comparisons, rather than in-depth benefit-cost ratios, rates of return, or detailed cost-effectiveness analyses employing systematic economic methodologies. The quality of the cost analyses was insufficient for a comprehensive understanding of the cost-effectiveness of these interventions. Appendix 22 summarizes the sources and analysis for this section.

We classified eight projects as having sufficient reliability for cost analysis (i.e., meeting acceptable and medium reliability standards). Three projects demonstrated acceptable reliability: Fadama III (World Bank 2020), CCDP (IFAD 2018), and FOF (Dragojlovic et al. 2020). These projects provided a range of comprehensive cost information, along with rigorous economic analysis methodologies, detailed funding source breakdowns, benefit-cost ratios, sensitivity analyses, and transparent reporting from authoritative sources, such as World Bank Implementation Completion Reports and IFAD project completion documents.

An additional five projects in Bangladesh showed adequate reliability standards: CCRIP (IFAD 2019), SAFAL (Kuijpers 2020), AFP (WorldFish 2008), AGEP (Orbicon/NCG 2019), and TiSeed (Ragasa, Amewu, et al. 2022). These projects provided acceptable cost information, but with some limitations in documentation completeness, cost disaggregation, or methodological transparency, which prevented them from achieving the highest reliability standards. Appendix

22 also presents two examples of projects with disparities in cost and economic evaluation information quality, hence, receiving lower reliability classifications.

Comparative analysis of cost-effectiveness

This section presents details of three projects (Fadama III, CCDP, and FOF) with acceptable reliability that demonstrate robust cost-effectiveness across different contexts.

The **Fadama III project** represents a significant agricultural development investment with a total actual cost of US$527.3 million (revised from an original budget of US$700 million), implemented in 36 Nigerian states across three phases from 2009 to 2019, with substantial additional financing. The project achieved exceptional cost efficiency, with total administrative and operational costs comprising only 3.4% of the total project budget, significantly lower than the typical 5-10% range for World Bank projects. Administrative expenses totaled US$13.68 million, with project monitoring comprising the largest component at US$4.97 million (36.4% of operational costs), followed by supervision at US$1.95 million (14.2%).

The ex-post economic evaluation revealed an Economic Internal Rate of Return (EIRR) of 47% for the overall project, exceeding the ex-ante projection of 29% and far surpassing the 12% opportunity cost of capital assumed. The project achieved an Economic Net Present Value (ENPV) of ₦69.2 billion (approximately US$226.9 million at 2020 values) with incremental net benefits of ₦34.5 billion (US$113.2 million approx.) over a 15-year period. Individual enterprise models within pond aquaculture achieve an internal rate of return (IRR) of 50%. The project's strength is demonstrated through a sensitivity analysis, which shows that returns remain stable under various price and cost scenarios. A 10% decrease in output prices reduced the EIRR by 28.9%, while the project could sustain a 39% increase in total costs before becoming unviable.

The **CCDP project**, implemented from 2012 to 2017 across 12 coastal districts in eastern Indonesia, demonstrated strong economic returns. The project operated with a US$44.9 million budget from a diversified financing structure: IFAD loan of SDR 15.87 million (US$32.8 million equivalent), Spanish Food Security Trust Fund loan of EUR 6.29 million (US$7.0 million), Government of Indonesia contribution of US$7.09 million, and beneficiary contributions of US$2.2 million. The financial performance analysis revealed that IFAD loan utilization reached 83.2% of allocated funds, while the Spanish Trust Fund achieved complete utilization at 99.7%.

The ex-post analysis showed an overall EIRR of 18.4% over 20 years (17.8% in real terms, assuming a 9% annual discount rate), which, while economically viable, was lower than the ex-ante estimate of 20.3%. The project benefited 503,500 people through 1,648 enterprise groups across diverse marine-based activities. Individual enterprise models exhibited significant variation in performance, with seaweed production achieving the highest Financial Internal Rate of Return (FIRR) at 119%, a benefit-cost ratio of 2.42, followed by trevally fish aquaculture (107%) and pelagic/demersal fishing (57%). The project's economic impact extended beyond direct participants through the development of its value chain. Fish processing activities, such as crackers (50%) and shrimp paste production (33%), created substantial value-added opportunities. Switching value analysis showed that seaweed production would remain viable unless benefits decreased by more than 59% or costs increased by more than 142%. The fiscal analysis revealed that the Indonesian government's investment generated significant returns, with tax revenues recovering 72% of the project costs. At the same time, farmers increased their net income by IDR 679 billion (approximately US$51 million).

Finally, the **FOF project** was a nutrition-sensitive agricultural intervention implemented across 4,642 households in rural Cambodia from 2016 to 2018, with an economic evaluation conducted

through an embedded pragmatic trial involving 652 households (334 control, 318 intervention) in 84 villages in the Kampot province. The project demonstrated strong cost efficiency through its integrated approach, combining horticulture, aquaculture, and poultry production with women's empowerment and nutrition education, resulting in a benefit-cost ratio of 1.62:1 with a plausible range of 0.43 to 6.11 based on 10-year projections. Program costs included start-up expenses of US$34 per household ($21 for household inputs, $12 for program design, and $1 for village model farm inputs), annual ongoing costs of US$35 per household ($30 for household inputs and $5 for village model farm support), plus training costs of US$31 initially and US$21 annually, and household labor valued at US$351 annually.

The aquaculture component proved remarkably successful, increasing small fish production participation by 106% (from 21.1% to 43.6%) and large fish farming participation by 74% (from 31.8% to 55.2%), with large fish production rising significantly from 14.6 kg to 23.0 kg annually among producing households. The study did not conduct a sensitivity analysis specifically for the aquaculture component; instead, it performed an overall program sensitivity analysis, which showed positive net benefits in 88.1% of iterations, with the benefit-cost ratio ranging from 0.43 to 6.11, depending on the discount rates and labor wage assumptions.

Methodological considerations in assessing cost-effectiveness

The Fadama III project employed an ex-post economic and financial analysis using impact evaluation methodology that compared outcomes with and without project intervention for representative enterprise models. This analysis included both incremental cost-benefit analysis for existing enterprises and full cost-benefit analysis for new business diversification activities. The methodology incorporated detailed shadow pricing adjustments, including exchange rate distortions, import/export parity pricing, and conversion factors for non-traded goods, resulting in a robust 15-year economic evaluation with sensitivity and switching value analyses.

In contrast, the Indonesian CCDP employed a mixed approach, combining financial and economic analysis across distinct enterprise models. It used illustrative production and marketing models to assess project viability, employing more conservative assumptions and a shorter 5-year implementation period, which was extended to 20 years for benefit projection.

Finally, the Cambodia FOF project used a cost-consequence analysis adapted from health economics. The study employed a cluster-randomized controlled trial with delayed intervention, measuring both agricultural production and health outcomes using disability-adjusted life years (DALYs). The analysis employed mixed models for production data and conducted a sensitivity analysis spanning 10 years to account for the integrated nutrition and agriculture interventions.

Scale, scope, and cost-effectiveness

The Nigerian Fadama III project, with its comprehensive multi-sectoral approach covering livestock, crop production, aquaculture, processing, and infrastructure development, achieved exceptional cost-effectiveness through diversified enterprise models. This reflects that large-scale, multi-component interventions can generate substantial economic returns when properly designed and implemented. The project's demand-driven approach enabled participants to select interventions that matched local conditions and market opportunities. This contributed to achieving a robust 47% overall EIRR.

The Cambodian FOF project employed a more targeted approach, implementing nutrition-sensitive agricultural interventions. Despite its smaller scale, the project achieved strong cost efficiency, demonstrating particular success in aquaculture components. In contrast, the

Indonesian CCDP, with a sectoral approach targeting coastal and marine-based enterprises, achieved more modest but still viable economic returns through concentrated interventions in fishing, aquaculture, and marine product processing. The project's smaller scale and geographic concentration enabled intensive capacity building and technology transfer, with individual enterprise models showing remarkable variation.

This comparison reveals that both comprehensive, multi-sectoral approaches, such as Fadama III, and more focused interventions, like the Cambodia and Indonesia projects, can achieve strong economic returns, albeit through different pathways. While focused interventions may achieve efficiency in specific activities, comprehensive approaches can generate synergistic benefits across diverse economic activities, justifying higher total costs through superior aggregate returns and broader poverty reduction impacts across rural communities.

Discussion

Summary of main results

We conducted a systematic review update of the effects of aquaculture interventions on productivity, income, nutrition and women's empowerment in L&MICs. We meta-analyzed 1,417 estimates from 53 impact evaluations of 40 programs. To explore factors that could influence the impact of aquaculture interventions on nutrition, we analyzed evidence from 33 qualitative, mixed-methods or quantitative descriptive studies that reported on underlying or enabling determinants of nutrition. We also reviewed cost information available for 23 aquaculture programs to explore possible patterns between implementation and cost-effectiveness.

To respond to research questions 1 and 2, we found no adverse effects for any of the outcomes analyzed, indicating that aquaculture programs are not harming their participants regarding any of the four pathways explored. However, there was insufficient evidence about spillover effects; hence, we could not fully address research question 3.

Specifically, we found that aquaculture programs significantly increased production volume, including fish yield and fish density. This is particularly the case for programs that uniquely focused on aquaculture activities, which were more effective in enhancing production volume than programs that also integrated other productive activities. While we did not find statistically significant average effects on production value and quality, providing direct resources to participants was more effective in increasing production value than other components along the aquaculture value chain (including the provision of technology, credit, training, technical assistance, and post-production assistance).

We found that aquaculture programs significantly improved income, including our aggregated measure, total household income, profits and revenues, but did not have a significant average effect on total and food expenditures. While providing post-production activities was less effective, delivering training and credit were effective strategies to increase total expenditure among program participants. In turn, the effect on food expenditure appeared to decrease with time, suggesting that households may turn from buying food to consuming their own production. Moreover, we found that aquaculture programs significantly increased productive assets. We did not identify significant effects on poverty headcount ratio or market participation, but we found significant improvements in the prices received from aquaculture activities.

We identified a higher number of evaluations reporting established measures of women's empowerment. Unlike the original review, we could meta-analyze this outcome group and found that aquaculture interventions increased the Women's Empowerment in Agriculture Index, and the Women's Empowerment Index. While we did not find statistically significant average effects on our aggregated measure or any of the three individual empowerment measures, the effect on women's mobility and economic empowerment appeared to increase the further the outcome is measured since program end, suggesting that these changes may take more time to realize.

We also identified more studies reporting nutrition measures compared to the original review and found that aquaculture programs improved the Food Consumption Score. We did not find statistically significant average effects on other food consumption, food security or nutrition outcomes. However, we found that delivering training sessions was more effective in improving the Household Dietary Diversity Score (HDDS) than other activities along the aquaculture value chain, and that the effect on HDDS appeared to increase with time. Likewise, programs that solely focused on aquaculture were more effective in improving fish consumption than programs covering other value chains. Although only about a quarter of all programs focused on nutrition, this evidence suggests that, with time and new skills, participants in aquaculture activities may be able to improve their food security and consumption.

By addressing research question 4, we aimed to delve deeper into the pathways that help connect aquaculture to improved nutrition and food security. We searched for evidence on three levels: immediate, underlying, and enabling conditions that affect food security and nutritional status. We did not identify evidence for immediate determinants, meaning dietary intake and health status. However, we found several themes related to the other two pathway levels, which connect with the quantitative findings for our four main outcome groups.

We found qualitative evidence highlighting increased production, assets, and income derived from these aquaculture activities as factors contributing to improved food security and expenditure. We also found limited evidence suggesting the potential of post-harvest technologies to enhance the shelf-life of fish. Yet, market dynamics and environmental conditions can constrain programs from improving food security. We identified qualitative evidence showing that high market prices can affect participants' motivation to sell produced fish, which competes with the decision of households to keep fish for their own consumption. This suggests a possible desire to increase income first. We also found that food availability and affordability, as well as distance to local markets can affect food accessibility and, hence, food expenditure and consumption. Environmental conditions can also present limitations to food security goals. The moderator analysis showed that programs from countries with very high exposure to climate threats were less effective in promoting food security than those with lower exposure. Qualitative evidence also documents experiences of climate barriers to food security among aquaculture participants, such as how seasonal weather patterns can affect food availability and fish prices. Additionally, qualitative evidence from Bangladesh indicated that high water salinity is a significant barrier to accessing drinking water.

Our qualitative evidence highlighted the constraints of aquaculture programs in changing household care practices toward achieving childhood nutrition goals. We found that despite receiving nutrition education through aquaculture programs, mothers and caregivers may be reluctant to feed fish or certain types of fish to their children. Reluctance was driven by beliefs about the suitability of fish for children (e.g., fear of fish bones or concerns about teeth development), the need to factor in preparation time, and children's dislike of fish or fish products. However, a few studies illustrated instances of children and caregivers who were receptive to fish or fish products promoted by aquaculture programs, appreciating their taste

and nutritional value. Limited qualitative evidence also suggested that receptiveness to changing cooking practices and disseminating nutrition information could be relevant to further social and behavior change, including improved household food consumption.

In terms of the role of women toward food security and consumption, we found examples of how cultural and logistical constraints (reflected through unequal treatment, movement restrictions, or limited childcare alternatives) can reduce women's ability to fully participate in and benefit equitably from aquaculture programs. When able to participate, we identified examples of women perceiving benefits from practicing aquaculture that could help challenge the status quo. This was signaled by developing skills, enhancing their status, and improving their decision-making power related to food consumption as well as other choices within the household. This finding aligns with the positive effects we identified on women's empowerment indices.

Overall, our quantitative and qualitative evidence suggests that aquaculture programs can be a reliable strategy to increase food consumption and expenditures, primarily through productive activities combined with complementary components such as training and nutrition education. However, the evidence also highlighted challenges to improving food preparation and consumption when programs do not align with local preferences and cultural norms, as well as barriers to enhancing food security when economic and environmental conditions are not integrated into programs. These contextual factors can sit outside the control of any one program (from individual tastes to climate shocks), which could help explain the lack of significant effects on other food security and child malnutrition measures.

To address research question 5, we identified cost information for 23 of the 40 projects reviewed. However, only three programs provided sufficiently reliable economic data for a meaningful assessment. This underscores a broader challenge in international development, where comprehensive economic evaluations remain scarce despite their critical importance for evidence-based policymaking. These three projects used distinct but rigorous methodological frameworks, which reflects not merely different reporting standards but also the inherent complexity of conducting robust economic evaluations across vastly different sectoral contexts.

Beyond methodological considerations, our analysis reveals compelling patterns regarding implementation approaches and their relationship to cost-effectiveness. The Nigerian Fadama III project's exceptional performance (47% EIRR with US$226.9 million NPV) demonstrates how demand-driven, community-based approaches can achieve superior economic returns across diverse enterprise models. Indonesia's CCDP demonstrates that focused sectoral interventions can yield substantial returns in specific value chains, with seaweed production achieving a 119% FIRR and benefit-cost ratios of 2.42, while maintaining economic viability even under adverse market conditions. The Cambodian FOF project demonstrates how integrated nutrition-sensitive approaches can achieve a strong cost efficiency (1.62:1 benefit-cost ratio) through targeted household-level interventions, particularly in aquaculture, where participation rates increased by over 100% in some components.

These findings suggest that the cost-effectiveness of development interventions may depend on matching the intervention design to local economic opportunities and institutional capacity. In Nigeria, the extensive multi-sectoral strategy yielded better overall returns through reduced risk and synergistic advantages across various agricultural and processing sectors. Indonesia's targeted marine-focused strategy demonstrated that concentrating investments in specific value chains can yield remarkable returns in particular areas. Cambodia's household-focused approach showed how smaller-scale, integrated interventions can achieve efficiency through

intensive capacity building and nutrition integration. Hence, multiple approaches can succeed economically when aligned with local contexts and operational capacities.

Overall completeness and applicability of evidence

We identified 57 rigorous evaluations of 40 programs across 11 countries. This represents an important increase compared to the original review (Gonzalez Parrao, Shisler, et al. 2021), which included 21 studies covering 13 programs across six countries. We observed a similar growth of both experimental and quasi-experimental studies. Thus, rigorous evaluations of aquaculture programs have increased and expanded its coverage since the original search.

However, we did not find additional qualitative and cost information for all these programs and countries. We found qualitative evidence from 30 programs across eight of the 11 countries reviewed to shed light on pathways to improve food security and nutrition. While we discussed themes around less immediate conditions of nutrition (underlying and enabling determinants), the most immediate determinant of nutrition (dietary intake and health status and disease exposure) remains unexplored. In turn, we also identified cost information for 21 programs in eight countries, although we had reliable cost analyses for only three programs, each implemented in a different country. This meant that we were not able to fully address the research question on cost-effectiveness of these aquaculture programs.

Despite our attempts to comprehensively search for relevant studies, the geographical coverage of this evidence could be a factor undermining the external validity of our results. We found studies from the Asian countries with highest aquaculture production except for China (Vietnam, (India, Indonesia, and Bangladesh; Wurmann 2024), and as in the original review, most of these programs are concentrated in Bangladesh (21 of 40 programs). Although Latin America and the Caribbean was not covered in the original review, we found only one study from Bolivia. We did not find evaluations of programs from middle-income countries. However, this may represent less of a gap, given that aquaculture is considered a strategy to reduce poverty and improve nutrition through consumption of aquatic foods (Garlock et al. 2022). Consumption of aquatic animal foods is far more prevalent in middle-income countries compared to low-income countries (FAO 2024b), suggesting a need to keep low-income countries in focus.

The increase in programs included in this update also meant a better coverage of aquaculture activities along the value chain. In contrast to the original review, where programs were mainly focused on pre-production or production stages, our evidence provides a more complete depiction of the aquaculture value chain, with high prevalence of training provision, post-production support, access to technology, and long-term technical assistance activities.

We also saw a considerably increase in the number of outcomes we could meta-analyze across the four outcome groups compared to the original review. While this allowed us to have a more complete picture of the effects of aquaculture programs, more evidence is needed, particularly related to nutrition and women's empowerment, as these analyses included a relatively smaller number of programs compared to productivity and income outcomes. For example, while in the original review we could not meta-analyze food security or women's empowerment measures, in this review we analyzed four established measures of food security (FCS, HDDS, FIES, and HFIAS) and two indices of women's empowerment (WEAI and WEI).

While we conducted moderator analyses for the majority of the 46 outcomes analyzed, we could not perform these analyses for 10 outcomes (production value, land area, price received, frequency of fish consumption, FCS, FIES, HFIAS, children's stunting, children's wasting, and

WEAI). Moreover, in many cases, we were not able to identify significant moderators, despite considering 18 variables. Thus, we could not fully explore potential sources of heterogeneity for the outcomes considered in the review.

Quality of the evidence

This review covered 1,417 estimates, which we assessed for risk of bias. We rated most of these estimates as having a high risk of bias, driven by the study design used. Evaluations based on randomized designs showed better quality than studies using quasi-experimental designs, particularly controlling for confounding factors and minimizing biases in selecting the treatment and control groups. In light of these results, the interpretation of the meta-analyses warrants some caution.

We also appraised the quality of the qualitative evidence. We assessed 19 of the 40 studies as high or moderate quality, 13 as low quality, and eight as critical quality (which we subsequently excluded from the analyses). As most of the qualitative synthesis is based on high-to-moderate quality evidence, we believe this provides a reasonable basis for the identified themes, allowing for a better understanding of the pathways from aquaculture activities to nutrition and food security outcomes.

Lastly, the fact that we were only able to identify reliable cost analyses for three of the 40 programs reflects that cost-effectiveness analyses remains an area with poor availability of quality data. However, this is not only an issue within aquaculture, but it extends across other development sectors (Hutchinson 2025).

Potential biases in the review process

One strength of this review is that we followed a tested framework, which was developed for conducting the original systematic review by Gonzalez Parrao, Shisler, et al. (2021). While conducting the review we abided to international standards to provide a rigorous quantitative and qualitative synthesis of evidence. We followed up on the clear recommendation from the original review to better understand the effectiveness and pathways through which aquaculture can affect all four outcome groups.

One possible bias is the time span covered by the review. We searched for quantitative studies in July 2024 and for qualitative evidence in November 2024. In light of the increase in rigorous evaluations of aquaculture programs, this implies that our review update may already be missing recent includable studies.

Another potential bias is the exclusion of some studies due to missing data. Twenty-two of the 56 included quantitative studies failed to report essential information to calculate effect sizes, such as standard deviation, t-statistic or p-value. In most cases, we retrieved these data through additional information from the study authors or by making reasonable assumptions when calculating effect sizes. This was not the case for four studies (published between 2007 and 2023). It is unclear how their inclusion may change the findings of the review.

Likewise, we could not search for additional cost data for six programs because they did not have clear and unique names. While finding additional data for these programs may not have extensively changed the overall state of the cost evidence of the aquaculture programs reviewed, it may have provided further insights into this area.

Lastly, we could not conduct citation tracking for the studies included in the qualitative synthesis. While we attempted to do this as good practice in reviews, resource constraints did not allow us to complete this task. It is possible that through citation tracking, we may have identified further relevant studies to enrich the qualitative synthesis.

Agreements and disagreements with other studies or reviews

This is an update of the review conducted by Gonzalez Parrao, Shisler, et al. (2021), which, to our knowledge, remains the most complete effectiveness synthesis of aquaculture programs in L&MICs. We found that evidence has more than doubled; hence, an update of the effectiveness analyses remains a need in the aquaculture space (Béné et al. 2016).

The review largely corroborated the original review's findings that aquaculture programs improve production and livelihoods. The original review reported no significant effects on production volume, while our update found a moderate to large increase in this outcome. In contrast, the original review reported a small increase in production value, a finding we could not replicate. In turn, both reviews identified a moderate rise in income, and we also found a relatively larger effect on assets and profit, although we synthesized slightly different measures. An area of disagreement is total and food expenditures, as we could not replicate the small increase identified in the original review. Still, these results resonate with our theory of change and align with evidence on small-scale fisheries' role in sustaining livelihoods (FAO 2024b; Béné et al. 2016).

Although more evaluations reported on established nutrition outcomes, which allowed us to explore more outcomes than in the original review, a mixed picture remains when comparing these results. We could not replicate the increase in fish consumption identified in the original review. However, we found a small increase in the Food Consumption Score. This disagreement may be related to baseline consumption levels across different settings and may reflect the challenges of boosting fish and food consumption across contexts. In this update, we still did not identify significant effects on children's malnutrition measures and women's BMI. The original review also reported a non-significant effect on men's BMI, the only outcome we did not reanalyze because we found no additional programs that reported it. These meta-analyses on nutritional status outcomes included the lowest number of programs in our review (between 2 and 4), restating the urgent need to build up the effectiveness evidence gap in this area (Béné et al. 2016).

The women’s empowerment outcome group represents the main change from the original review, which did not meta-analyze outcomes due to the scarcity and heterogeneity of measures reported. Instead, in this update, we explored aggregated indicators and individual measures, and found a moderate increase in the empowerment indices (Women’s Empowerment in Agriculture Index, Women’s Empowerment Index, and our aggregated measure). To our knowledge, no other review has presented these findings from quantitative synthesis.

The original review explored barriers and facilitators that can generally affect the effectiveness of aquaculture programs, and identified factors that affect program set up, participation and the level of productive activities. Our review replicated some of those findings when investigating factors that influence the implementation of programs to improve nutrition, dietary diversity or food security. For example, how local economic and environmental settings can affect production and livelihoods, and the role that social and cultural norms have in the participants’ involvement in programs, particularly for women. The finding that gender norms persistently

disadvantage women is highly recognized in the literature (Kruijssen, McDougall, and Van Asseldonk 2018; Mahmud et al. 2025; Rao et al. 2024). Moreover, because of the scope of our research question, this review was also able to discuss in more detail other pathways that help connect aquaculture activities to food consumption and security; for example, the role that individual preferences have when deciding to serve or consume fish within the household.

The area that this review update is not able to cover relates to the environmental effects of aquaculture practices, particularly in light of the international push for sustainable aquaculture (for example, the FAO Blue Transformation initiative promotes the triple goal of sustainable aquaculture growth, equitable benefits, and environmental conservation; FAO 2024b). Recent reviews have started to explore this area under a global scope. For instance, Liu et al. (2024) conducted a systematic review on the impact of aquaculture practices on wastewater pollution, while the review by Abu Samah et al. (2021) synthesized the evidence of climate adaptation practices in aquaculture communities. A next step would be to identify and synthesize the effectiveness evidence available on L&MICs.

Authors' conclusions

Implications for practice and policy

The main implication from this review update is that aquaculture is a safe bet for improving fish farmers' productivity and livelihoods, which works well across contexts and productive systems. Aquaculture can also support women's empowerment and inclusion, as well as household food security and consumption. However, decision-makers should take further considerations to ensure aquaculture's promise to affect food security and nutrition outcomes is achieved.

Policymakers can expect aquaculture programs to be a viable instrument for boosting production and income-related outcomes, which can also act as pathways to enhance household food security and expenditure. To have a better chance to improve these outcomes, the design of future programs should consider:

- Focusing on productive activities specific to the aquaculture value chain, instead of integrating other productive activities.
- Providing fish farmers with direct inputs, training, and access to credit to increase productivity and household expenditures.
- Investing in developing and providing post-production technologies to enhance the preservation of aquaculture produce.

Decision-makers should also consider tailoring future programs to local norms, preferences, economic dynamics and environmental settings to contribute to women's empowerment, food security, and consumption outcomes. Examples of these considerations include:

- Assessing women's travel and childcare arrangements can facilitate their equitable involvement in the aquaculture value chain, which in turn, can empower their position within the household.
- Providing informational and practical training sessions to raise awareness of the nutritional value of fish, the low risk of choking with fish bones, and to reinforce cooking practices

can improve fish consumption. Promoting the production of fish species that meet local tastes, can also favor this goal.

- Accounting for local market dynamics that affect food security, particularly when there are competing motivations between selling aquaculture produce and improving household consumption of nutritious food.

- Integrating adaptation mechanisms to cope with environmental shocks that can also minimize the environmental impact of aquaculture activities, especially in countries with high exposure to climate threats.

Overall, decision-makers should assess the merits of intervention strategies depending on the goals aiming to achieve, the local context, and operational capacities. Multiple approaches can succeed economically when the intervention design is aligned with local economic opportunities, social norms, and institutional capacity.

Implications for research

- **Geographical gaps**: future program evaluations should focus on filling current geographical gaps, particularly in countries across Latin America and the Caribbean (e.g., Brazil and Ecuador) and Sub-Saharan Africa (e.g., Zambia and Malawi) with active aquaculture sectors, but where we found few or no studies.

- **Rigorous and high-quality evaluations**: when possible, aquaculture programs should be evaluated using experimental designs, as these are the gold standard. However, the if this is not feasible, programs evaluated using quasi-experimental designs should ensure that they account for common biases, particularly controlling for relevant factors (e.g., fish types produced, other programs potentially affecting similar outcomes), and ensuring the suitable comparability of groups (e.g., by accounting for pre-treatment trends in the observed outcomes).

- **Keep using established outcome measures**: more evidence is needed on the effects of aquaculture on women's empowerment and nutrition. This would help better understand what works across contexts and any differential impacts for specific groups. Researchers and commissioners are encouraged to keep using, and requesting the use of, established measures, such as the Household Diet Diversity Score or the Women's Empowerment in Fisheries and Aquaculture Index. Collecting anthropometry measures for adults and children is also essential to unpack aquaculture pathways that can contribute to realizing nutritional status outcomes. s

- **Explore environmental outcomes**: researchers and commissioners of future evaluations should consider expanding this literature by investigating understudied areas around small-scale aquaculture, such as measuring the environmental effects these programs. This would help build up knowledge on sustainable aquaculture, aligning with the Global Biodiversity Framework and the Sustainable Development Goals.

- **Detailed programs costs**: decision-makers and researchers should plan to collect, analyze, and report detailed program costs covering uptake, all components delivered, and its performance. Comprehensive economic evaluations remain scarce despite their critical importance for evidence-based policymaking, particularly in the current context of reduced development funding.

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Data Availability Statement

The data set used for the quantitative, qualitative and cost evidence syntheses, along with their corresponding code files and codebooks, will be made available in 3ie's Dataverse https://dataverse.harvard.edu/dataverse/3ie.

Declarations of interest

The authors declare having no conflict of interest related to this review. We acknowledge that some of the authors of the original systematic review are also co-authors of this update. In addition, one of the projects included in the review was evaluated by 3ie; however, the 3ie review team has conducted this update independently from the 3ie evaluation team and their input did not affect the findings and conclusions from this review update.

Plans for updating this review

There are no current plans for updating this review.

Differences between protocol and review

When calculating effect sizes, we did not randomly evaluate 10% of the effect sizes for the correct use of the formulae. Instead, we created a code to automate this process. Hence, this step was no longer necessary.

When conducting risk of bias assessment, we did not compare reported outcomes from studies to available pre-analysis plans to assess the reporting bias. We limited this assessment to identifying if the study reported the presence of a pre-analysis plan.

Online appendix

https://3ieimpact.org/sites/default/files/2026-02/Online-Appendix-Aquaculture-SR-update-Report-Preprint.pdf

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