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Impact of adoption of better management practices and nutrition-sensitive training on the productivity, livelihoods and food security of small-scale aquaculture producers in Myanmar

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Abstract

Small-scale aquaculture is a major source of food in Myanmar. Beyond its importance for food security and nutrition, small-scale aquaculture contributes to the livelihoods of many rural households and is a potentially valuable strategy for rural development. However, small-scale aquaculture producers have limited access to improved production technologies and information, which hampers the productivity and socioeconomic performance of small-scale aquaculture systems. In this study we assessed the impact of the adoption of better management practices and exposure to nutrition-sensitive training by 379 small-scale aquaculture producers in the Sagaing and Shan regions of Myanmar. We focused on whether and how the exposure to these interventions affected household food security through improvements in productivity and livelihoods. We used Propensity Score Matching to compare the performance of groups that were exposed to the intervention for one or two years, for seven impact variables. Exposure to the intervention had a positive effect for most impact variables, with differentiated effects among variables, group comparisons and regions. In terms of food security, beneficiaries had significantly higher dietary diversity (measured as the Food Consumption Score, FCS), but there were no significant differences for fish self-consumption (measured in kg/week). Longer exposure to the interventions produced significantly higher positive effects across most impact variables for the 2-year beneficiaries compared to 1-year beneficiaries and control groups. Our study suggests that the length of exposure to such interventions can be important in mediating the actual impact of small-scale aquaculture systems on household food security and livelihoods. Sustained help to small-scale producers should be considered in initiatives and development projects seeking to enhance the food security and rural development of small-scale aquaculture systems in Myanmar, and beyond.

Keywords Extension · Development intervention · Better Management Practices (BMPs) · Rural development · Propensity Score Matching (PSM) · Sustainability

1 Introduction

In many parts of the world, and especially in developing countries, fish production does not meet demand, and hence production expansion might be needed (Merino et al., 2012; Naylor et al., 2021). Such expansion should be pursued simultaneously with improvements and rationalization in distribution channels to ensure adequate fish production while avoiding unsustainable expansion and over-production (Naylor et al., 2021).

With an annual growth rate of ≈9% globally, aquaculture is one of the fastest expanding agrifood sectors (Garlock et al., 2022; Toufique & Belton, 2014). It contributes strongly to efforts aimed at enhancing food security (Azra et al., 2021; Irwin et al., 2021). Aquaculture currently accounts for approximately 46% of total global fish production (179 Mt) and 52% of total fish consumption (FAO, 2020a). Aquaculture output has increased sharply to meet the growing demand for animal-sourced protein following global population increases and improvement of living standards, from 14.9 Mt (between

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1986 and 1995) to 82.1 Mt (in 2018) (FAO, 2020a). The continuous development of aquaculture systems could be a viable option to enhance food security and improve livelihoods, especially for small-scale producers in developing countries (FAO, 2020b).

Small-scale aquaculture[1] accounts for ≈50% of the current global aquaculture output (FAO, 2020b). Due to its importance for the livelihoods of small-scale producers, it is increasingly seen as a promising way to reduce poverty and improve livelihoods (Bernzen et al., 2022), food security (Irwin et al., 2021), human nutrition (Ahmed & Waibel, 2019), and gender equality (Dam Lam et al., 2022), especially in developing countries (FAO, 2020b; Filipski & Belton, 2018). Enhancing the sustainability of small-scale aquaculture has received particular attention as a strategy to meet several intertwined national and local development aspirations (FAO, 2020b; Pradeepkiran, 2019), especially in Asia, where much of global small-scale aquaculture production is concentrated (Belton et al., 2017; Karim et al., 2020).

One way to improve the rural development potential and overall sustainability of small-scale aquaculture is through the promotion, adoption and proper implementation of better management practices (BMPs) (Giri, 2017). BMPs is an umbrella term that encompasses very diverse production and management practices seeking to enhance the socioeconomic and environmental performance of aquaculture systems (Naylor et al., 2021; van Duijn et al., 2018; Waite et al., 2014). BMPs range from guidance for selecting the most appropriate fish species and production sites in a locality, to rules for selecting and optimizing the operational characteristics of small-scale aquaculture systems (Belton et al., 2018; Giri, 2017; Howerton, 2001). A necessary pre-condition for the subsequent realization of expected positive impacts is the successful and sustained uptake of BMPs (and their proper implementation) (Bone et al., 2018; Karim et al., 2020). However, this is often constrained by the unavailability of appropriate information and resources to small-scale producers (Bush et al., 2021; N'souvi et al., 2021; Ragasa et al., 2022a; World Bank, 2007).

The promotion and uptake of BMPs is usually pursued through integrated interventions from state or non-state organizations that seek to improve livelihoods, food security and other development objectives via the provision of relevant resources and information (Karim et al., 2020; Filipski & Belton, 2018; Tezzo et al., 2018; Murshed-E-Jahan & Pemsl, 2011; Aweke et al., 2021). Extension services are key aspects of such interventions, as they provide information to familiarize beneficiaries with the components of interventions, and how they can be used and implemented properly (Dam Lam et al., 2022; Karim et al., 2020).

Studies on aquaculture and in broader agricultural contexts have found that the eventual impact of such interventions depends on the sustained adoption of relevant technology and on the duration/length of exposure to related extension services (Bambio et al., 2022; Barrett et al., 2021; Kumar et al., 2018). This is because the continuous exposure to extension support allows producers to fully assimilate the technicalities of interventions, adjust farm expenditure, and appreciate how the different intervention components can affect the farm enterprise (Murshed-E-Jahan & Pemsl, 2011; Barrett et al., 2021). Studies have found mixed impacts relative to duration of exposure and adoption, depending on the technology promoted or the impact category investigated (Aramburu et al., 2019). While some studies imply that longer durations of exposure to and adoption of the recommended practices/technologies can lead to better outcomes (see Barrett et al., 2021; Bambio et al., 2022), it is not always clear whether this materializes in reality. Furthermore, many relevant impact assessment studies do not consider the duration of exposure or adoption to the recommended practices/technologies as a variable, hence missing possibly valuable policy- and practice-relevant information (Habtewold, 2021; Makate et al., 2019; Paul & Vogl, 2013; Tran et al., 2020). These knowledge gaps are particularly pronounced for small-scale aquaculture interventions (Aung et al., 2023; Karim et al., 2020), and should be appreciated better if we are to understand the food security and rural development potential of such interventions.

Myanmar is one of the major aquaculture producers globally, with an annual aquaculture output of > 1 Mt and an estimated annual value of > USD 1.4 billion in 2018 (FAO, 2020a; Karim et al., 2020). Aquaculture is responsible for about 36% of total national fish production (FAO, 2020a), contributing significantly to animal-source protein consumption (Karim et al., 2020). The sector comprises approximately 220,000 fish producers, mainly operating small-scale farms (FAO, 2020a; Karim et al., 2020; Tezzo et al., 2018). With close to 24.8% of the national population living below the poverty line and recording one of the highest food insecurity levels in Asia (Central Statistical Organization et al., 2019), the rapidly expanding aquaculture sector already plays (and will continue to play) a significant role in the national economy and food security of Myanmar. Several studies have identified aquaculture as a sector with a huge potential to boost food security, livelihoods and rural development nationally (Karim et al., 2020; Aung et al., 2023; Filipski & Belton, 2018; Belton et al., 2017; Garlock et al., 2022).

Nevertheless, there are major differences within the aquaculture sector in Myanmar, which can affect its development potential. Half of all fish farms are smaller than 4 ha and

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[1] Small-scale aquaculture refers to aquaculture production in small ponds (typically < 10 acres; < 4 ha) (Belton et al., 2017), which may be self-owned or leased, and may be partly used for fish culture and crop irrigation (Belton et al., 2017; Karim et al., 2020).

thus considered small-scale, but these account for only 4% of the total production area (Belton et al., 2015; Filipski & Belton, 2018). Larger-scale farms (> 40 ha) comprise just 7% of farms but account for nearly 60% of the total area under aquaculture. The sector is skewed towards large farms, which reflects legacies of inequalities in land access and policies, exacerbated by unequal access to inputs, poor support from extension services and low levels of improved technology adoption among small-scale producers (Belton et al., 2018). With the obvious possibility that larger farms have better access to financial and non-financial support (including extension), small-scale producers continue to face substantial challenges in enhancing pond productivity, and escaping poverty and food insecurity (Karim et al., 2020; Aung et al., 2023). Consequently, many interventions are being increasingly implemented across the country targeting small-scale aquaculture producers to stimulate the uptake of BMPs and facilitate access to good quality inputs, as a means to enhance their productivity, livelihoods and food security (Aregu et al., 2017; Belton et al., 2017; Karim et al., 2020). But, there is a general lack of evidence about the success of such interventions, and the factors affecting it.

Thus the aim of this study was to assess the impacts of an intervention that combined the uptake of BMPs and nutrition-sensitive information among small-scale aquaculture producers in Myanmar. We focused on impacts related to pond productivity, livelihoods, and food security, which are critically low in many rural areas of Myanmar. Beyond assessing these impacts, we sought to advance knowledge about the effects of different durations of exposure to the intervention and adoption of BMPs. To achieve this, we used a robust analytical approach based on propensity score matching to capture impact differentiation among one-year beneficiaries (1Y) and two-year beneficiaries (2Y). Section 2 of this paper outlines the intervention and the methodology. Section 3 presents the main results of the study, while Sect. 4 critically discusses the findings and draws key policy and practice recommendations for enhancing the sustainability and development potential of small-scale aquaculture systems in Myanmar and other developing countries.

2 Study site and intervention

In our study we focused on the impact of (and temporal dimensions of exposure to) the Myanmar Sustainable Aquaculture Programme (MYSAP Inland) intervention implemented by WorldFish, with support from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). This programme was implemented in three culture cycles between 2018 and 2020, and targeted small-scale aquaculture producers in different parts of the country. Small-scale aquaculture was defined as

household-level production in ponds < 0.5 acres (< 0.2 ha) in area, that held water for at least six months per year. These small-scale aquaculture ponds were the entry point for the delivery of the intervention, extension, and training services, because these households were considered particularly vulnerable, less-endowed, poor and food insecure (Bondad-Reantaso & Prein, 2009; Aung et al., 2023). More broadly, such small-scale producers in Myanmar tend to employ traditional and generally unsustainable and low-productivity production practices (Aung et al., 2023; Karim et al., 2020).

The eligible small-scale producers were divided in groups, and received key aquaculture resources and a comprehensive information package about BMPs and nutrition. The main elements of the intervention included: (a) materials for all beneficiaries (specifically fish seed, crop seeds, weighscale, pH paper, training materials) (b) training on small-scale aquaculture and improved human nutrition for all beneficiaries, (c) feed production equipment and preparation costs for one pond for each farmer group, (d) follow-up visits every two weeks for technical support to each group.

The aquaculture production aspect of the intervention focused on BMPs that covered: (a) pond location and preparation before stocking, (b) fish species, stocking density and feeding, (c) pond water quality and fertilization, and (d) integrated vegetable production. The nutrition aspect of the intervention focused on emphasizing the nutritional value of eating a diverse diet and the health benefits of regular consumption of fish (including small indigenous fish species consumed whole). The nutritional components contained information for fish-based recipes and food groups. Box S1 in the Supplementary Material provides more information about the different components of the intervention.

The recruitment of the beneficiary producers and the outreach activities happened in two cohorts (in the 2018–2019 and 2019–2020 seasons) and was conducted mostly through face-to-face training. MYSAP Inland worked with households for a maximum of two years, meaning households received either one year or two years of intervention support. The intervention supported the development of 20 leaflets and posters and 77 training videos in the Myanmar language, as well as local languages including Big Shan, Lahu and Arka. The extension materials were distributed at face-to-face training sessions to reinforce key take-home messages and learning points. During the COVID-19 pandemic and the state of emergency, the intervention adopted a flexible approach and transitioned from face-to-face meetings, visits and material dissemination to increased use of virtual platforms (Green Way app) and a private member-only Virtual Fish Culture Learning Group on Facebook. Box S2 in the Supplementary Material highlights in more detail how the training was delivered and some of the main aspects covered for each BMP.
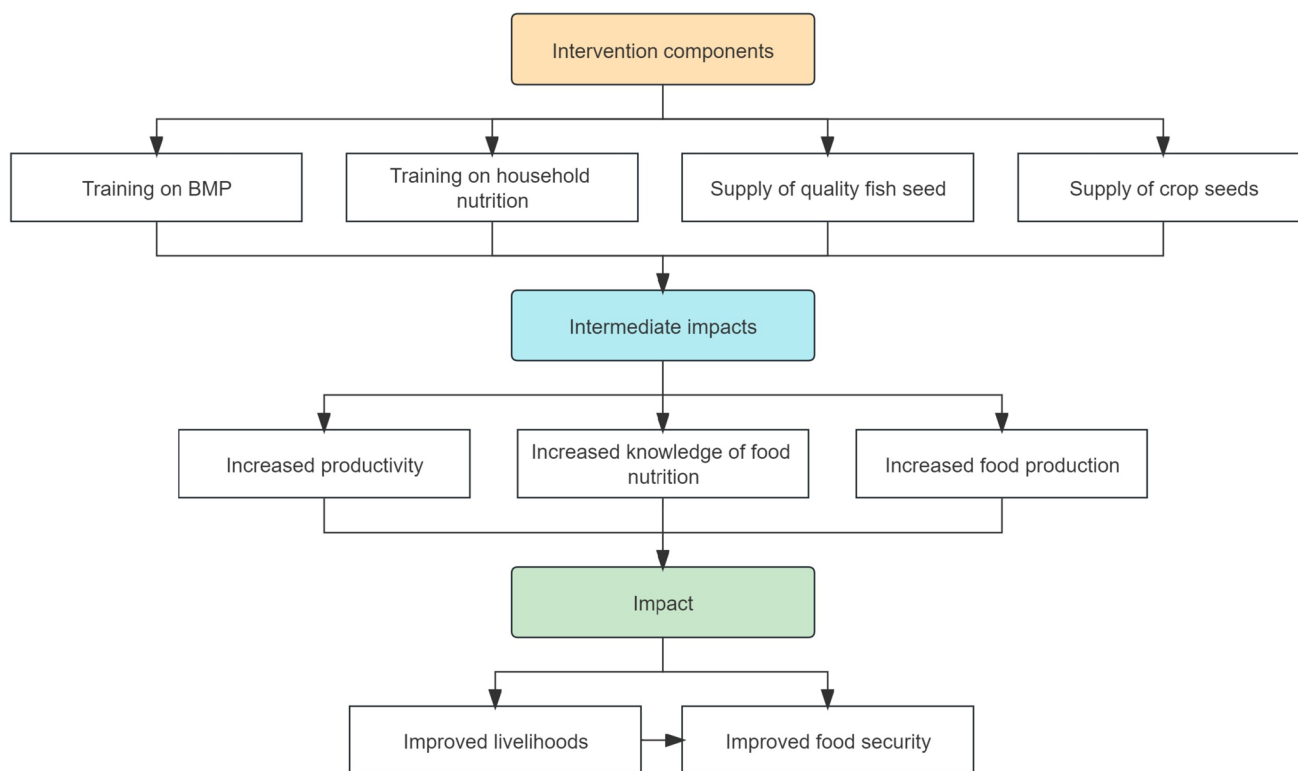
Fig. 1 Impact pathway of the aquaculture study intervention

In Fig. 1 we outline the main components and expected outcomes of the intervention. Overall, the intervention reached a total of 1,504 direct-beneficiary households in five townships located in the Shan State, the Sagaing Region and the Mandalay Region of Myanmar. Following a comprehensive scanning of possible interventions areas in the country the specific regions were selected because they are characterized by (a) appropriate production conditions and availability of land for aquaculture, (b) prior existence of small-scale fish ponds, (c) a significant number of small-scale aquaculture producers, and (d) low development, in terms of low income and livelihoods, low food/nutrition security, and a general lack of access to sanitation and related infrastructure. Table 1 outlines the characteristics of the intervention townships.

Once the intervention areas were selected, the intervention team undertook a rigorous beneficiary selection process to identify the households expected to benefit the most from the intervention. Intervention beneficiaries were small-scale producers that (a) owned or cultivated fishpond(s) < 0.5 acres (< 0.2 ha), and (b) were vulnerable in terms of livelihoods and food security. To identify these beneficiary households the intervention team extracted farmer data about household characteristics, farm production and total household income from the WorldFish Myanmar database, to identify the most vulnerable households in the study area. The 1504 direct beneficiary households identified and selected for intervention based on these characteristics received exactly the same support outlined above in two cohorts (1 Year and 2 Year beneficiaries).

3 Methodology

3.1 Data collection and experimental design

We conducted a structured household questionnaire survey via phone, using Kobotoolbox as the data collection platform (for more information refer to: https://www.kobotoolbox.org/). The survey was undertaken between 15 March and 2 April 2021. The original plan was to collect data using face-to-face interviews, but COVID-19 pandemic restrictions and an unstable political situation in Myanmar impeded in-person data collection.

The questionnaire contained open- and close-ended questions to elicit the expected impact of exposure to the aquaculture intervention on productivity, livelihoods and food security. The survey modules comprised of: (a) basic socio-economic and demographic household characteristics, (b) aquaculture practices, (c) household income and expenses, (d) aquaculture production and output, and (e) food security in terms of dietary diversity (Food Consumption Score, FCS) (WFP, 2008).

Table 1 General characteristics of the aquaculture intervention areas in Myanmar

| | Mandalay Region | Sagaing Region | Shan State | |
			Southern Shan	Eastern Shan
Environmental Characteristics				
Land Type	- Mostly plains with some medium highlands near to Shan states	- Combination of highlands and plains	- Two third of the land are hilly, and about one third is plains	- Mainly hilly, with exception of Tachileik Township
Land Use	- Settlements (15%) - Cultivated land (8%) - Net cultivated land (38%) - Agriculture land (1%) - Industrial land (0.2%) - Reserve forest (23%) - Raw forest (2%) - Waste land (12%)	- Settlements (9%) - Net cultivated land (54%) - Agriculture land (0.2%) - Industrious land (0.1%) - Reserve forest (22%) - Raw forest (6%) - Raw land (1%) - Waste land (7%)	- Settlements (9%) - Cultivated land (3.14%) - Net cultivated land (12%) - Agriculture land (2%) - Reserve forest (15%) - Raw forest (39%) - Raw land (5%) - Waste land (15%)	- Settlements (3%) - Net cultivated land (5%) - Agriculture land (1.8%) - Reserved forest (9%) - Raw forest (29%) - Raw land (22%) - Waste land (30%)
Climate	- 8.2 rainy days per year (2018) - 4.22 cm annual rainfall	- 25.6 rainy days per year (2018) - 16.42 cm annual rainfall	- 30.6 rainy days per year (2018) - 11.01 cm annual rainfall	- 48 rainy days per year (2018) - 25.49 cm annual rainfall
Socioeconomic and demographic characteristics				
Religion	- 95.7% Buddhism - 3.0% Islam - 1.1% Christianity - 0.2% Hinduism	- 92.2% Buddhism - 6.5% Christianity - 1.1% Islam - 0.1% Other religion - 0.1% Hinduism	- 81.7% Buddhism - 9.8% Christianity - 6.6% Tribal religion - 1% Islam - 0.5% Other religion - 0.4% No religion	
Age structure	- The highest proportion of population (19%) is 10–19 years old	- The highest proportion of population (19%) is 10–19 years old	- The highest proportion of population (21%) is 10–19 years old	
Education	- Males tend to be more educated than females	- Males tend to be more educated than females	- Males tend to be more educated than females	
Livelihoods	- 48% employed - 26% engaged in household work - 22% seeking employment and/or not employed - 4% are disabled and/or mentioned nothing	- 46% employed - 28% engaged in household work - 23% seeking employment and/or not employed, - 3% are disabled and/or mentioned nothing	- 46% employed - 31% engaged in household work - 18% seeking employment and/or no employment - 5% are disabled and/or mentioned nothing	
Poverty	- 13.2% poverty rate	- 30.7% poverty rate	- 28.6% poverty rate	

Source (WorldFish, 2020)

We collected information from a total of 702 respondents divided across beneficiary and non-beneficiary (control) groups. We focused on intervention beneficiaries from the Shan and Sagaing regions, because the specific intervention in these areas could lend itself to proper impact assessment. The intervention there targeted individual small-scale producers with the on-farm interventions described in the previous section, as opposed other regions/townships where the intervention experienced major implementation challenges or focused only on community ponds, which would have made impact elicitation for households very uncertain. For these reasons we focused on three out of the five beneficiary townships in the intervention areas, namely Kale and Shwebo (in Sagaing), and Kengtung (in Shan) (Fig. 2).

Considering the significant information-sharing component of the intervention, there is a high likelihood of spillover effects through informal communication between beneficiaries and non-beneficiaries, which may affect the final outcomes (Dompreh et al., 2021a; Fenger et al., 2017). For this reason, we did not select control groups from the same townships that received the intervention. Instead, we recruited non-beneficiary participants from "control townships", i.e., townships where the intervention was not rolled out, but that are within the same region and share similar environmental and socioeconomic characteristics to the intervention townships. Overall, we selected six control townships in the Shan (Tachilek, Taungyi, Pindaya, Pekhon) and Sagaing (Wetlet, Khin U) regions (Fig. 2).

A list of beneficiaries was obtained from the MYSAP intervention database (n = 1504 households) and a list of control or non-beneficiary aquaculture farmers that shared similar characteristics was obtained through WorldFish
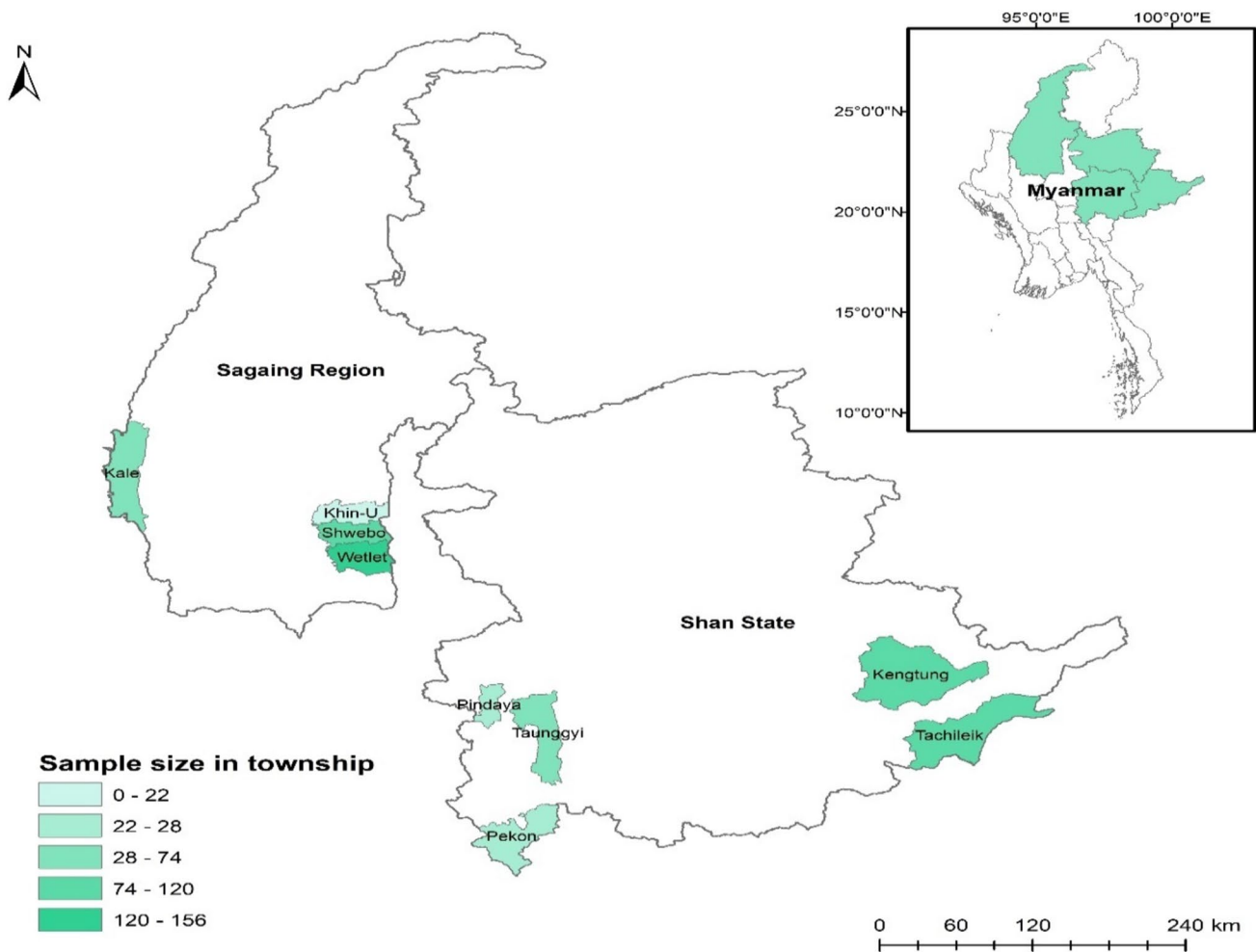
Fig. 2 Map of the aquaculture intervention areas in Myanmar

Myanmar databases. We used a proportionate distribution rule to select aquaculture farmers in each township based on the intensity of exposure to the intervention and the number of years benefitting (1Y and 2Y Beneficiaries). We selected the beneficiaries and non-beneficiaries from the above databases by assigning random numbers to potential respondents using a random number generator in Excel.

From the 702 selected households across all study groups, we used 379 households for the final analysis after removing households that were income outliers or had zero aquaculture harvest in the year prior to the survey. Table 2 contains the distribution of the sample in the intervention and control townships before and after removal.

3.2 Data analysis

3.2.1 Impact variables

We explored the development outcomes of exposure to the intervention for a series of impact variables related to

productivity, livelihoods, and food security (see Fig. 1). Overall, we focused on seven major impact variables as outlined in Table 3.

Impact on pond productivity was measured in terms of yield and total harvested fish. Yield was measured by dividing the quantity of total pond fish harvested (in kg) by the total size of ponds (in acres). The expectation was that the interventions will enhance the quantity of fish harvested in a given pond area, hence increasing pond yield.

Livelihood impact was measured in terms of total household income and fish-related revenue. Revenue is generated by multiplying the quantity of fish harvested by the price sold per unit. The total fish revenue was measured by summing the fish revenue from both water and open water fishing measured in thousands Myanmar Kyat (1000MMK). Fish revenue per unit area was measured by dividing fish revenue obtained from ponds by pond size, measured in 1000MMK/acre. Total household income (measured in 1000MMK) is assessed by summing all major and minor income sources including income from pond and open water,

Table 2 Sample size distribution across sites and groups

Respondent type	Region	Township	Sample before removal		Sample after removal	
			Year 1	Year 2	Year 1	Year 2
Treatment	Sagaing	Kale	40	34	25	20
		Shwebo	60	60	57	54
	Shan	Kengtung	50	56	45	44
Control	Shan	Tachileik	105		39	
		Taungyi	64		18	
		Pindaya	27		13	
		Pekhon	28		9	
	Sagaing	Wetlet	156		43	
		Khin U	22		12	
Total sample			**702**		**379**	

Source: MYSAP endline survey data (2021)

agriculture, remittance, and own business. It was expected that by increasing fish output and improving knowledge about possible market options the fish revenue and income of beneficiary households will increase.

Food security impact was measured in terms of fish consumption and dietary diversity. Fish consumption was measured by the quantity of fish consumed in the household in the seven days prior to the survey, and is measured in kilograms of consumed fish per week (Kg/week). Diet diversity was measured using the Food Consumption Score (FCS), which captures the consumption frequency of different food groups in the week prior to the survey (WFP, 2008). When calculating the FCS, the different food groups consumed in the past seven days are weighted and the weighted food group scores are summed and placed within determined thresholds of food security (namely poor, borderline and acceptable), with high FCS denoting higher food diversity, and thus higher food security (WFP, 2008). The expectation is that the intervention will enhance the food security of targeted farmers for both metrics, by allowing for greater fish self-consumption (for the former) and increasing crop species and allowing for food purchases (for

the latter). The FCS has been used widely to measure diet diversity as a proxy of food security (Dam Lam et al., 2022; Dompreh et al., 2021b; Gasparatos et al., 2022), when other measures such as daily caloric intake or wasting/stunting cannot be measured effectively (Hendriks, 2015; Wessells & Brown, 2012).

For each impact variable we initially estimate descriptive statistics such as means and t-tests to identify discernible patterns between groups. This analysis is reported in Sect. 4.1–4.2 and was conducted through R programming, with the data imported from Excel using *readxl* package. However, such descriptive analysis is inadequate for establishing causality between exposure to an intervention and the actual impact, largely due to endogeneity, selection bias and systematic errors from researchers (Dehejia & Wahba, 2002; Dompreh et al., 2021b). Section 3.2.2 outlines and justifies the approach used for impact elicitation.

3.2.2 Impact elicitation: Propensity score matching (PSM)

There are several different approaches to elicit the impact of development interventions including assessing changes

Table 3 Description of impact variables

Impact category	Impact variable	Description	Unit	Expectation
Productivity	Yield	Measure by dividing quantity of pond fish harvest by pond size	Kg/acre	+
	Total fish harvested	Measured by summing quantity of both pond and open water harvested fish	Kg	+
Livelihoods	Total fish revenue	Measurement by summing fish revenue from ponds and open water	1000MMK	+
	Fish revenue per unit area	Revenue is quantity of fish harvested multiplied by price sold per unit Measured by dividing fish revenue by pond size	1000MMK/acre	+
	Household income	Measured by summing all income lines in the household	1000MMK	+
Food security	Fish consumption	Measured by calculating the quantity of fish consumed in 7 days	Kg/week	+
	Diet diversity (Food Consumption Score)	Measured by consumption of 8 food groups and weighted (WFP, 2008)	Score	+

Source: MYSAP endline survey data (2021)

in the performance of beneficiary households over time through panel data (i.e., before and after the interventions) (Murshed-E-Jahan & Pemsl, 2011; Khandker & Koolwal, 2016) or counterfactual analysis (i.e., comparisons with groups that did not receive the intervention) (e.g., Aung et al., 2023; Dam Lam et al., 2022). Counterfactual techniques vary in their ability to randomize the assignment of beneficiaries to the intervention, and include randomized control trials (Ragasa et al., 2022b; Verbowski et al., 2018) and matching approaches (Ntiri et al., 2022; Tran et al., 2020).

In this study, due to the lack of baseline data for the intervention households, we followed a counterfactual approach to elicit impacts. We opted for a matching approach, as while there is the likelihood of selection bias and other biases[2] it is very challenging to implement fully experimental techniques such as randomized control trials in large-scale development interventions that contain multiple components (e.g., training, technology transfer), which can be readily adopted partly or fully by non-targeted households (Nakano & Magezi, 2020; Yitayew et al., 2021).

In particular we utilized the propensity score matching (PSM) method to control, to the extent possible, for biases and associated endogeneity[3] problems. The PSM reduces restrictions in distributional assumptions and thus allow for impact estimation without imposing arbitrary assumptions and functional forms as other methods (Jalan & Ravallion, 2003; Rubin & Thomas, 2000).[4] Due to this flexibility, the PSM has been used to assess the impact of development interventions, including related to small-scale aquaculture

(Ahmed et al., 2019; Dam Lam et al., 2022; Islam et al., 2015; Mitiku et al., 2017; Tran et al., 2020).

We conduct three levels of comparisons: (a) "1Y Beneficiaries" vs. "Control", (b) "2Y beneficiaries" vs. "Control", and (c) "2Y Beneficiaries" vs. "1Y Beneficiaries". This enables the estimation of both how the exposure to the intervention and the length of exposure can affect the impact variables (Sect. 3.2.1). We expect that both "2Y Beneficiaries" and "1Y Beneficiaries" will have better performance across all impact variables than "Control" households. Furthermore, "2Y Beneficiaries" are expected to perform better than "1Y Beneficiaries".

The PSM approach is performed in two stages. First, the intervention beneficiary status (1 = beneficiary, 0 = control) is regressed against household and pond characteristics that simultaneously affect outcome variables and beneficiary status (Ahmed et al., 2019; Apiors & Suzuki, 2018; Dompreh et al., 2021b; Etuk & Ayuk, 2021). In this study, we used a probit regression model during the first stage of the PSM, with the covariates shown in Table S1 (Supplementary Material).

Second, the generated propensity scores are used to match treatment and control farmers. Here, we used three different matching algorithms, namely the Nearness Neighbor, the Radius Caliper and the Kernel matching (Caliendo & Kopeinig, 2008). For each comparison we choose the matching algorithm that yields lowest biases after comparing the balancing test results using different metrics (e.g., mean bias, Pseudo R-squared). Tables S20–S22 contains the matching algorithm for every comparison group and the balancing tests results.

In PSM studies two main treatment effects are normally estimated: the Average Treatment Effect (ATE) and the Average Treatment Effect on the Treated (ATT) (Mitiku et al., 2017; Stuart, 2010; Caliendo & Kopeinig, 2008). Here we estimate the ATT for each outcome variable, as it measures the impact of the intervention for the treated group, compared to the ATE that measures impact for the population (Dompreh et al., 2021b; Froehlich et al., 2018; Caliendo & Kopeinig, 2008).

We standardized the ATT across the mix of different physical units of outcome variables in different regions using the percentage change (PC) (Eq. 1.)

$$PC = \frac{ATT_{i,j}}{C_{i,j}} \tag{1}$$

where $ATT_{i,j}$ is the average treatment effect on the treated (ATT) for impact i in group j, $and C_{i,j}$ is the treatment effect of control for impact i in group j.

Finally, we conducted a sensitivity analysis to assess whether the estimates could be affected by unobservable characteristics, as a means of reducing the unavoidable problem of controlling for only observable characteristics

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[2] Selection bias occurs through: (a) external selection (i.e., selection of a group of people to target through the intervention), and (b) self-selection (i.e., own voluntary decision to participate in the intervention) (Bareinboim & Pearl, 2012; Caliendo & Kopeinig, 2008). Other types of biases are introduced through the (a) lack of compliance with the intervention (i.e. failure or unwillingness to implement intervention properly), and (b) participation in interventions from non-beneficiaries (i.e. non-beneficiaries that decide to implement the interventions partly or fully due to perceived benefits) (Armijo-Olivo et al., 2022; Hernan et al., 2004).

[3] Endogeneity primarily occurs in three ways, namely simultaneity, measurement error and omitted variables. Simultaneity occurs when two variables are codetermined; measurement error occurs when it is difficult to perfectly measure a variable (hence imposing some noise); omissions occur when a variable correlates with an independent variable and the error term (Caliendo & Kopeinig, 2008; Ojo & Baiyegunhi, 2020).

[4] Other analytical options we considered were: (a) Instrumental Variable Regression that uses external source of variations to determine the treatment effect, but may result in imprecise and biased outcomes as it is difficult to identify valid (strong) instrumental variables (Martens et al., 2006); (b) Endogenous Switching Regression (ESR) model that controls for both observable and unobservable characteristics (Ayalew et al., 2019; Hasebe, 2020) but imposes strong/restrictive distributional assumptions (Main & Reilly, 1993; Mendola, 2007).

(and thus possibly retaining some inherent biases). We determined the likely extent (gamma level) at which the unobserved variables impose biases in the causal estimation (Hirano & Imbens, 2001; Caliendo & Kopeinig, 2008). Here, we use the Rosenbaum bounds for the sensitivity analysis (Caliendo & Kopeinig, 2008). High sensitivity to hidden bias is present if the conclusions change for values of Gamma just slightly > 1, while low sensitivity occurs if the conclusions change at large values of Gamma (Olmos & Govindasamy, 2015; Rosenbaum, 2002). While a sensitivity analysis demonstrates the level to which inferences can be influenced by unobservable biases at different magnitudes, it does not confirm whether hidden biases are indeed present (Mudombi et al., 2021; Rosenbaum, 2002). Also, sensitivity to hidden bias does not necessarily imply that a study design is faulty, nor is low sensitivity necessarily a laudable achievement (Rosenbaum, 2002).

For the PSM analysis we used Stata15 Software, with the results reported in Sect. 3.3. The results of the PSM analysis are summarized in Sect. 4.1 through a spot matrix map created through *ggplot2* package in R.

3.3 Study limitations

Despite the robust data collection and analysis approach, the study had certain limitations that could have inserted biases and uncertainties. These were mostly beyond the control of the research team, but are summarized below to understand possible limits to generalization.

First, unavoidably for the reasons explained in Sect. 3.2.2 we had to rely on cross-sectional data and a matching counterfactual approach which may give rise to: (a) hidden bias as participants with certain characteristics might be included in the intervention (e.g., wealthy or highly productive farmers); (b) endogeneity due to measurement error, variable omission and reverse causation. To avoid such issues, we relied on: (a) rigorous selection of intervention beneficiaries and study participants, (b) rigorous selection of control area and control group participants, and (c) sensitivity analysis. For (a) the intervention team identified all vulnerable small-scale farmers in the study area [ponds < 0.5 acres (< 0.2 ha), low incomes] regardless of other sociodemographic and production characteristics (Sect. 2)[5] and we selected participants through a randomization process among all beneficiaries. For (b) we identified control areas and participants sharing the same characteristics as beneficiaries, but are not affected from the intervention (see next point). For (c), we selected appropriate

matching variables and conducted a sensitivity analysis (Sect. 4.3). Although we believe that collectively these steps enhanced the robustness of the results, other factors such as the COVID-19 pandemic may have imposed some advantages/disadvantages to beneficiaries and controls that may insert hidden bias in this study but are unfortunately difficult to track.

Second, considering the heavy training/knowledge transfer component of the intervention (Sect. 2) there may be knowledge-sharing between beneficiaries and control groups. To avoid this, we selected control groups located in communities at a reasonable distance from beneficiary areas to reduce possible knowledge spill-over effects. Although we cannot preclude the possibility of spill-over effects, we believe that such risks are minimized considering the distance between communities.

Finally, we relied on phone interviews due to the constraints posed by the COVID-19 pandemic and the political turmoil in Myanmar. This caused instances of respondent fatigue (leading to the termination of some surveys) and precluded enumerators to "read" the physical gestures of the respondents. To avoid grossly under- or over-reported data, we trained enumerators to enquire deeper if the elicited data seemed unreasonable, and conducted an outlier analysis to omit problematic data (Table 2).

4 Results

4.1 Socio-demographic characteristics of the study groups

Table 4 outlines key socio-demographic characteristics of the sampled households. In Sagaing region, farmers from all groups had similar (and small) pond sizes ranging between 0.25–0.29 acres (≈0.10–0.12 ha). In terms of education, 2Y Beneficiaries tended to have higher levels of education compared to 1Y Beneficiaries and Control farmers. Gender distribution was fairly equal among study groups, with males dominating the small-scale aquaculture sector in the region.

Intervention beneficiaries in Sagaing region benefited from a substantially higher frequency of extension visits compared to control farmers, which is expected considering that this was a key aspect of the intervention. However, 2Y Beneficiaries received more visits by extension compared to 1Y beneficiaries (17.7 vs. 14.3 visits per year respectively), which again points to differentiation between beneficiaries.

In Shan state, 2Y Beneficiaries had larger ponds than 1Y Beneficiaries (0.18 vs. 0.11 acres; 0.07 vs. 0.04 ha), which were much smaller than those of control groups (0.26 acres; 0.11 ha) (Table 4). 1Y Beneficiaries tended to have higher educational attainment (7.49 years) compared

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[5] This notwithstanding, farmers may decide to under-report their production or income in order to benefit from an intervention (Cheema et al., 2018). This is beyond the control of the intervention team.

Table 4 Socio-demographic characteristics of study groups

Area	Group	Age (years)	Education (years)	Household size (members)	Pond size (acres)	Gender (1 = male)	Frequency of extension visits (times/year)	Years of aquaculture experience
Sagaing Region	1Y Beneficiaries	51.34	6.26	4.01	0.29	0.73	14.31	8.69
	2Y Beneficiaries	50.36	6.45	3.82	0.25	0.73	17.72	10.82
	Control	45.95	6.34	4.42	0.26	0.75	0.16	2.29
Shan state	1Y Beneficiaries	47.47	7.49	3.87	0.11	0.73	1.16	5.40
	2Y Beneficiaries	49.32	6.91	3.84	0.18	0.48	1.75	12.98
	Control	45.80	6.11	4.77	0.26	0.82	0.04	3.19
Pooled sample	1Y Beneficiaries	49.97	6.69	3.96	0.23	0.73	9.65	7.59
	2Y Beneficiaries	49.97	6.62	3.83	0.23	0.64	11.76	11.62
	Control	45.86	6.20	4.63	0.26	0.79	0.09	2.58

Source: MYSAP endline survey data (2021)

to 2Y Beneficiaries (6.91 years), and Control households (6.11 years). Although the number of extension visits was much lower than Sagaing region,[6] 2Y Beneficiaries had more extension visits (1.75 visits/year) compared to 1Y Beneficiaries and Control households (1.1.6 and 0.04 visits/year respectively). There was gender parity of household head for 2Y Beneficiary households, and an almost complete dominance of male-headed households in the Control group.

4.2 Adoption of BMPs and aquaculture performance between groups

The adoption of BMPs was generally higher for intervention beneficiaries compared to control farmers, with "2Y Beneficiaries" reporting a higher degree of BMP adoption across their ponds. This was observed both for the pooled sample (Fig. 3) and the individual regions (Figs. S1, S2, Supplementary Material). Since the promotion of BMPs was one of the main goals of the intervention (Sect. 2), this was expected. However, it is noteworthy that 2Y Beneficiaries adopted more BMPs than other beneficiaries, suggesting that longer exposure to the intervention is linked to higher adoption of

BMPs. Also, although almost all BMPs were universally adopted by 2Y Beneficiaries, the use of chemicals and drugs is still not prevalent, possibly due to high costs associated with this practice.

Table 5 outlines the different performance indicators between 1 and 2Y Beneficiaries and Controls in all study regions. In the Sagaing region, 1Y Beneficiaries had significantly lower yields of fish (152.9 kg/acre; 377.7 kg/ha, $p < 0.10$), lower total fish harvested (39.6 kg, $p < 0.10$) and lower total fish revenue (1000MMK 183.99, $p < 0.01$) compared to Control producers. On the other hand, 1Y Beneficiaries had significantly higher FCS than Control producers by 25.1 points ($p < 0.01$) and higher weekly fish consumption (not significant). Similarly, in the Sagaing region 2Y Beneficiaries had significantly higher fish revenue per unit area (831.31 1000MMK/acre; 2,053.33 1000MMK/ha, $p < 0.10$), food consumption score (23.26 points, $p < 0.01$) and weekly fish consumption ($p < 0.1$) compared to Control producers. Comparison between 2 and 1Y Beneficiaries in Sagaing showed that the former had significantly higher fish revenue per unit area ($p < 0.05$) and yield ($p < 0.01$). In terms of food security there was no statistically significant difference for fish consumption and diet diversity between the two groups.

In the Shan region the t-test comparison suggests that 1Y Beneficiaries had significantly higher diet diversity (by 31.06 points, $p < 0.01$) compared to Control producers, but the differences for all other impact variables were not significant. 2Y Beneficiaries reported significantly higher household income (by 1000MMK 1,077.46, $p < 0.01$), fish revenue per unit area (by 248.53 1000MMK/acre; 613.87 1000MMK/ha, $p < 0.10$), yield (by 188.50 kg/acre; 465.60 kg/ha, $p < 0.01$), weekly fish consumption (by 0.87 kg, $p < 0.05$) and diet diversity in terms of FCS (by 37.60 points, $p < 0.01$) compared to Control producers. Even though 2Y Beneficiaries also reported higher total

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[6] The frequency of follow-up technical support visits in Shan State was lower than in Sagaing Region due to a different set of factors. In particular, the elevated and mountainous terrain of the Shan State area, the poor road system and because many villages were often cut off and unreachable in the monsoon season, made logistical planning of field activities much more difficult than in the Sagaing Region. Moreover, Shan State has a distinct cold season which can be off putting for extension staff that have to travel to the field on motorbikes. Finally, while variable over time, there were generally greater restrictions on travel to villages in the Shan State during both the COVID-19 pandemic and the state of emergency periods than there were in the Sagaing Region. However, many of these issues were sought to be mitigated through knowledge dissemination via online tools (Box S2, Supplementary Material).
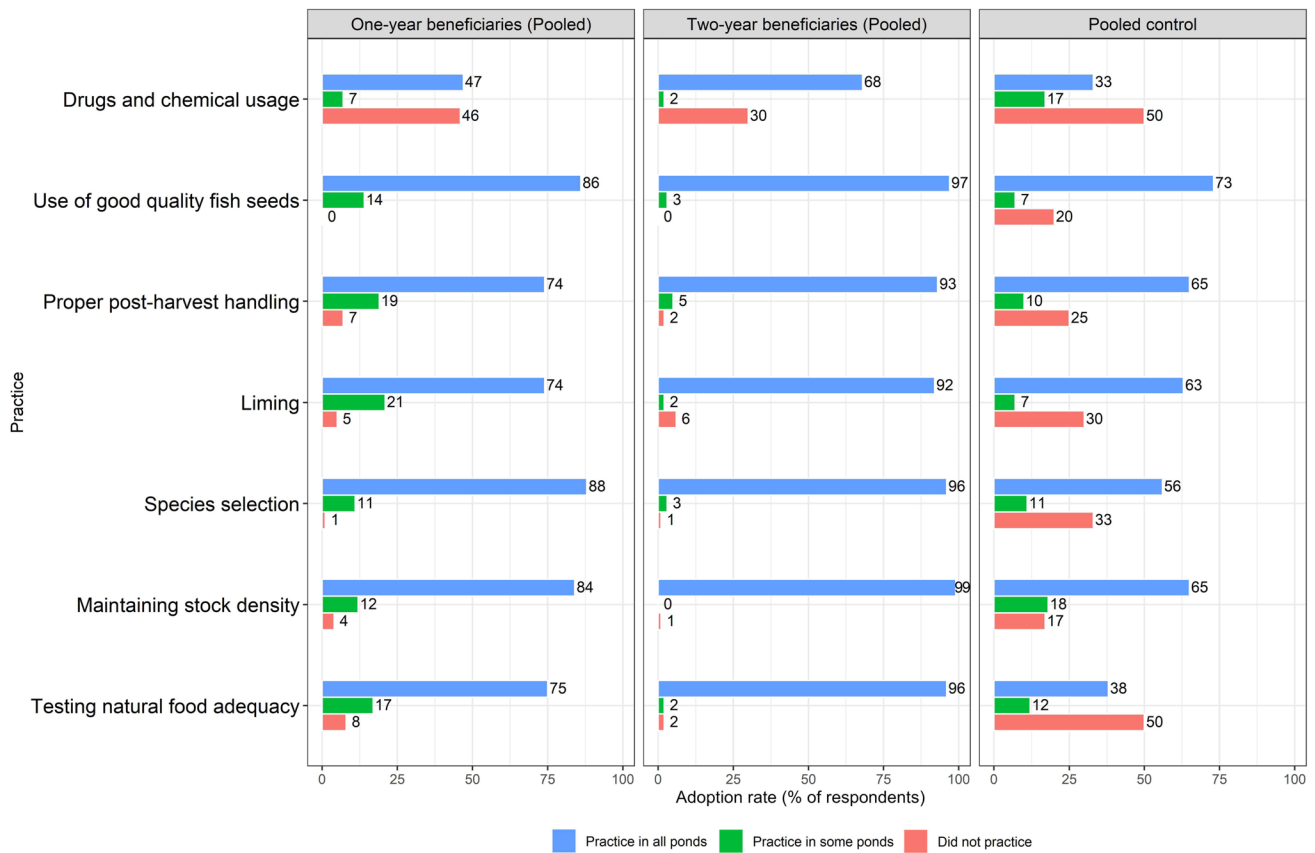
Fig. 3 Adoption of aquaculture BMPs among study groups aggregated across all study sites in Myanmar

amounts of fish harvested and fish revenue than Control producers, the differences were not statistically significant. Comparisons between 2 and 1Y Beneficiaries shows that the former have significantly higher total household income (by MMK 837.9, $p < 0.05$), fish revenue per unit area (by 209.1 1000MMK/acre; 516.48 1000MMK/ha, $p < 0.10$), total fish harvested (by 43.74 kg, $p < 0.01$), total fish revenue (1000MMK 63.7, $p < 0.01$), weekly fish consumption (0.81 kg, $p < 0.1$) and diet diversity in terms of FCS (by 6.54 points, $p < 0.05$).

For the pooled sample, the results of the t-test between 1Y Beneficiaries and Control producers, suggest that the former recorded higher fish revenue per unit area (by 181.34 1000MMK/acre; 447.90 1000MMK/ha, $p < 0.01$), total fish revenue (by 1000MMK 63.69, $p < 0.10$), weekly fish consumption (by 0.49 kg, $p < 0.05$) and diet diversity in terms of FCS (by 27.47 points, $p < 0.01$). Similarly, 2Y Beneficiaries have higher total household income (by 1000MMK 452.52, $p < 0.05$), fish revenue per unit area (by 724.74 1000MMK/acre; 2,514.85 1000MMK/ha, $p < 0.01$), yield (by 314.18 kg/acre; 776.02 kg/ha, $p < 0.01$), consumption (by 1.25 kg, $p < 0.01$), and diet diversity (by 28.84 points, $p < 0.01$), when compared to the Control producers. Finally, comparison between 2 and 1Y Beneficiaries

for the pooled sample, suggested that the former perform significantly better only for yield (by 294.03 kg/acre; 726.25 kg/ha, $p < 0.01$), total fish harvested (by 24.88 kg, $p < 0.01$), fish revenue per unit area (by 543.39 1000MMK/acre; 1,342.17 1000MMK/ha, $p < 0.05$) and weekly fish consumption (by 0.79 kg, $p < 0.10$).

4.3 Impact of exposure to intervention on aquaculture performance and food security

Table 6 outlines the PSM estimation for the pooled sample, and Tables 7, 8 for the Sagaing region and Shan state separately. For each comparison, we selected different matching techniques following tests that yielded the least mean bias, lowest Pseudo R-squared and the highest p-value LR test. Supplementary Material Tables S2–S16 and S20–S22 contain full results for the matching and the balancing, and Figs S5–S19 the histogram of propensity scores.

For productivity, the results showed that pooled 1Y Beneficiaries had significantly larger total fish production (by 37.34 kg, $p < 0.1$) compared to the Control producers. 2Y Beneficiaries significantly improved yields (by 231.85 kg/acre; 572.67 kg/ha, $p < 0.1$) comparted to Control producers. Comparisons between 2 and 1Y Beneficiaries show

Table 5 Comparison of aquaculture performance between study groups

Region	Group	Productivity		Livelihoods			Food security	
		Yield (kg/acre)	**Total fish harvested (kg)**	**Total fish revenue (1000MMK)**	**Fish revenue per unit area (1000MMK/acre)**	**Total household income (1000MMK)**	**Fish consumption (kg/week)**	**Diet diversity (FCS score)**
Sagaing Region	**1Y Beneficiaries**	425.70 (30.07)	107.93 (8.39)	201.75 (19.95)	803.14 (83.07)	1710.58 (191.908)	2.63 (0.25)	67.26 (1.31)
	Control	578.66 (89.97)	147.55 (25.39)	385.75 (67.87)	730.12 (95.98)	1702.58 (187.53)	2.18 (0.28)	42.15 (2.60)
	Difference	-152.93* (82.23)	-39.61* (23.16)	-183.99*** (60.61)	73.018 (128.33)	8.00 (280.25)	0.45 (0.38)	25.11*** (2.66)
	2Y Beneficiaries	827.41 (156.92)	124.37 (14.46)	244.21 (47.37)	1561.43 (391.62)	1726.62 (209.05)	3.43 (0.55)	65.41 (1.61)
	Control	578.66 (89.97)	147.55 (25.39)	385.75 (67.87)	730.12 (95.98)	1702.58 (187.53)	2.18 (0.28)	42.15 (2.60)
	Difference	248.75 (197.99)	-23.18 (27.57)	-141.54* (80.25)	831.31* (462.16)	24.04 (291.52)	1.25* (0.68)	23.26*** (2.92)
	2Y Beneficiaries	827.41 (156.92)	124.37 (14.46)	244.21 (47.37)	1561.43 (391.62)	1726.62 (209.05)	3.43 (0.55)	65.41 (1.61)
	1Y Beneficiaries	425.73 (30.07)	107.93 (8.40)	201.75 (19.95)	803.14 (83.07)	1710.58 (191.90)	2.63 (0.25)	67.26 (1.31)
	Difference	401.68*** (152.34)	16.44 (152.34)	42.46 (0.15)	758.29** (382.04)	16.03 (283.27)	0.80 (0.59)	-1.85 (2.06)
Shan state	**1Y Beneficiaries**	239.23 (48.76)	14.14 (2.66)	23.57 (6.52)	258.50 (81.89)	1777.43 (255.11)	1.57 (0.28)	72.16 (2.32)
	Control	172.99 (27.22)	41.46 (8.88)	74.59 (10.82)	219.04 (95.14)	1537.90 (160.85)	1.52 (0.14)	41.09 (2.70)
	Difference	66.23 (51.49)	-27.31** (11.95)	-51.02*** (15.17)	39.46 (140.50)	239.53 (287.10)	0.052 (0.28)	31.06*** (3.98)
	2Y Beneficiaries	361.50 (44.47)	57.89 (6.87)	87.26 (16.07)	467.57 (91.95)	2615.36 (293.08)	2.39 (0.39)	78.69 (1.82)
	Control	172.99 (27.22)	41.46 (8.88)	74.59 (10.82)	219.04 (95.14)	1537.90 (160.851)	1.52 (0.14)	41.09 (2.70)
	Difference	188.50*** (49.29)	16.43 (12.96)	12.67 (18.81)	248.53* (144.87)	1077.46*** (306.84)	0.87** (0.34)	37.60*** (3.87)
	2Y Beneficiaries	361.50 (44.47)	57.89 (6.87)	87.26 (16.07)	467.57 (91.95)	2615.36 (293.08)	2.39 (0.39)	78.69 (1.82)
	1Y Beneficiaries	239.23 (48.76)	14.14 (2.66)	23.57 (6.52)	258.50 (81.89)	1777.43 (255.11)	1.57 (0.28)	72.16 (2.32)
	Difference	122.27 (66.07)	43.74*** (7.30)	63.69*** (17.20)	209.08* (122.98)	837.93** (388.00)	0.81* (0.48)	6.54** (2.96)
Pooled	**1Y Beneficiaries**	359.64 (27.07)	74.70 (6.79)	138.62 (15.10)	610.16 (65.06)	1734.27 (152.79)	2.27 (0.20)	68.99 (1.19)
	Control	339.50 (43.64)	85.00 (12.46)	202.31 (31.37)	428.81 (71.69)	1605.49 (121.88)	1.79 (0.15)	41.53 (1.91)
	Difference	20.14 (52.00)	10.30 (14.40)	63.69 (35.43)	181.34* (97.13)	128.78 (194.42)	0.49** (0.24)	27.47*** (2.28)
	2Y Beneficiaries	653.68 (101.68)	99.58 (9.86)	185.69 (31.03)	1153.55 (252.11)	2058.01 (174.50)	3.04 (0.38)	70.36 (1.35)
	Control	339.50 (43.64)	85.00 (12.46)	202.31 (31.37)	428.81 (71.69)	1605.49 (121.88)	1.79 (0.15)	41.53 (1.91)
	Difference	314.18*** (106.13)	14.58 (16.18)	16.62 (44.33)	724.74*** (248.55)	452.52** (208.99)	1.25*** (0.38)	28.84*** (2.40)
	2Y Beneficiaries	653.68 (101.68)	99.58 (9.86)	185.69 (31.03)	1153.55 (252.11)	2058.01 (174.50)	3.04 (0.38)	70.36 (1.35)
	1Y Beneficiaries	359.64 (27.07)	74.70 (6.79)	138.62 (15.10)	610.16 (65.07)	1734.27 (152.79)	2.27 (0.20)	68.99 (1.19)
	Difference	294.03*** (101.94)	24.88** (11.83)	47.07 (33.76)	543.39** (252.17)	323.74 (231.12)	0.79* (0.42)	1.37 (1.80)

Standard error in parenthesis. Source: MYSAP endline survey data (2021)

*p < 0.10; **p < 0.05; *** p < 0.01

Table 6 Propensity Score Matching (PSM) analysis for pooled sample

Impact category	Impact Variable	Groups	Treatment effect (ATT)	Rosenbaum bounds gamma
Productivity	**Yield (kg/acre)**	1Y Beneficiaries vs Control	-87.27 (65.16)	1.8
		2Y Beneficiaries vs Control	231.85* (128.79)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	283.53*** (104.02)	1.1
	Total fish harvested (kg)	1Y Beneficiaries vs Control	-37.34* (22.11)	2.8
		2Y Beneficiaries vs Control	-14.04 (22.73)	1.6
		2Y Beneficiaries vs 1Y Beneficiaries	23.39 (14.45)	1.0#
Livelihoods	**Total fish revenue (1000MMK)**	1Y Beneficiaries vs Control	-163.98***(62.15)	5.6
		2Y Beneficiaries vs Control	-112.48* (63.33)	4.0
		2Y Beneficiaries vs 1Y Beneficiaries	42.62 (42.69)	-#
	Fish revenue per unit area (MMK/acre)	1Y Beneficiaries vs Control	34.26 (111.07)	-#
		2Y Beneficiaries vs Control	593.93** (294.66)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	515.96* (266.32)	-#
	Total household income (1000MMK)	1Y Beneficiaries vs Control	184.25 (198.01)	-#
		2Y Beneficiaries vs Control	600.80** (254.37)	1.2
		2Y Beneficiaries vs 1Y Beneficiaries	382,769.80 (262,800.00)	-#
Food security	**Fish consumption (kg/week)**	1Y Beneficiaries vs Control	0.31 (0.25)	-#
		2Y Beneficiaries vs Control	1.00*** (0.42)	1.1
		2Y Beneficiaries vs 1Y Beneficiaries	0.69 (0.47)	-#
	Diet diversity (FCS score)	1Y Beneficiaries vs Control	25.89*** (2.55)	27.2
		2Y Beneficiaries vs Control	28.12*** (2.37)	32.0
		2Y Beneficiaries vs 1Y Beneficiaries	1.48 (2.03)	-#

Parentheses in ATT column denote the standard error; Parentheses in the group column denote the final sample for each group after common support. "#" in the sensitivity analysis column indicate comparisons with low gamma scores that are indications of possible indication to hidden bias. Source: MYSAP endline survey data (2021)

*p < 0.10; **p < 0.05; *** p < 0.01

that longer exposure to interventions increased both the yield and the total amount of fish harvested, though only the effects on pond yield were statistically significant (increase by 283.53 kg/acre; 700.32 kg/ha, p < 0.01).

The results from individual regions/states (Sagaing and Shan) also shows that interventions improved the yield of beneficiary farmers with a much more pronounced improvement for 2Y beneficiary farmers (Tables 7, 8). Similar performance patterns were also observed for total fish harvested. This could be related to the continuous use of improved technologies and available extension services to farmers. These findings point to how the access to relevant technologies and inputs in aquaculture production can lead to increased production performance.

In terms of livelihoods for the pooled sample (Table 6), 1Y Beneficiaries had significantly lower total fish revenue (by 163.98 1000MMK, p < 0.01). In contrast, exposure to the intervention for two years (2Y Beneficiaries) significantly increased total household income (by 1000MMK 600.80, p < 0.05) and fish revenue per unit area (by 593.93 1000MMK/acre; 1,467.00 1000MMK/ha, p < 0.05) compared to Control producers, but significantly reduced total

fish revenue (by 112.48 1000MMK, p < 0.1). Comparison between 2 and 1Y Beneficiaries shows that exposure to interventions for two years increased significantly only fish revenue per unit area (increase by 515.96 1000MMK/acre; 1,274.42 1000MMK/ha, p < 0.1), despite some positive indications for several other impact variables.

The enhanced livelihoods of beneficiaries were also seen in the increased fish revenue per unit area and total household income of beneficiary farmers in each region (Tables 7, 8). But beneficiary farmers recorded lower total fish revenue compared to control farmers (though farmers improved their performance over the years). Generally, the two-year cohort of beneficiary farmers performed much better compared to one-year beneficiaries in the study regions. This implies clear possibilities that relevant aquaculture interventions may enhance the livelihoods of smallholder farmers who may have lower access to relevant technologies and inputs.

Finally, in terms of food security, in the pooled sample (Table 6) 1Y Beneficiaries improved both their weekly fish consumption and diet diversity compared to Control producers, with the impact being however statistically significant

Table 7 Propensity Score Matching (PSM) analysis for the Sagaing region

Impact category	Impact Variable	Groups	Treatment effect (ATT)	Rosenbaum bounds gamma
Productivity	**Yield (kg/acre)**	1Y Beneficiaries vs Control	-188.22* (106.47)	2.5
		2Y Beneficiaries vs Control	248.21 (202.17)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	403.67** (185.89)	7.3
	Total fish harvested (kg)	1Y Beneficiaries vs Control	-58.72* (31.69)	2.3
		2Y Beneficiaries vs Control	-35.61 (37.22)	2.2
		2Y Beneficiaries vs 1Y Beneficiaries	17.67 (16.74)	1.5
Livelihoods	**Total fish revenue (1000MMK)**	1Y Beneficiaries vs Control	-246.82***(89.29)	5.7
		2Y Beneficiaries vs Control	-184.83 (114.51)	5.7
		2Y Beneficiaries vs 1Y Beneficiaries	46.82 (48.36)	1.8
	Fish revenue per unit area (1000MMK/acre)	1Y Beneficiaries vs Control	17.10 (151.83)	-#
		2Y Beneficiaries vs Control	850.78 (470.01)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	768.30* (464.79)	5.0
	Total household income (1000MMK)	1Y Beneficiaries vs Control	96.86 (282.38)	-#
		2Y Beneficiaries vs Control	98.55 (404.38)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	79.10 (287.72)	-#
Food security	**Fish consumption (kg//week)**	1Y Beneficiaries vs Control	0.53 (0.40)	-#
		2Y Beneficiaries vs Control	1.16 (0.71)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	0.77 (0.56)	-#
	Diet diversity (FCS score)	1Y Beneficiaries vs Control	25.03*** (3.17)	24.0
		2Y Beneficiaries vs Control	23.56*** (3.15)	16.0
		2Y Beneficiaries vs 1Y Beneficiaries	2.25 (1.97)	1.2

Parentheses in ATT column denote the standard error; Parentheses in the group column denote the final sample for each group after common support. "#" in the sensitivity analysis column indicate comparisons with low gamma scores that are indications of possible indication to hidden bias. Source: MYSAP endline survey data (2021)

*p < 0.10; **p < 0.05; *** p < 0.01

only for diet diversity (by 25.89 points, p < 0.01). 2Y Beneficiaries also improved weekly fish consumption (by a worthwhile 1.00 kg, p < 0.01) and dietary diversity (by 28.12 points, p < 0.01) compared to Control producers. Comparisons between 2 and 1Y Beneficiaries showed that exposure to interventions for two years increased both the weekly fish consumption and diet diversity of the former, but the effects were not statistically significant.

For individual regional/state estimates, beneficiaries in both Sagaing region and Shan state improved their dietary diversity (FCS) compared to control farmers (Tables 7, 8). Beneficiary farmers also recorded increased fish consumption per week compared to control farmers. In these two indicators of food security, 2Y beneficiaries recorded increased food security in comparison to 1Y beneficiaries. Again, these findings are indications that the aquaculture interventions did have a positive impact on the food security situation of farmers in the short term.

To explore the robustness of the analysis we conducted a sensitivity analysis using the Rosenbaum Bounds method (see last column of Tables 6–8) (see Tables S5–S19 in Supplementary Material for full analysis). The results suggest

varied levels of sensitivity to hidden bias that could likely affect the estimates. Low gamma values (1 or lower) suggest higher sensitivity to hidden bias, while greater values of gamma suggest lower sensitivity to hidden bias. We identified possible sensitivity to hidden bias for some comparisons, both for the pooled sample (Table 6) and the regional analyses (Tables 7, 8). Overall fewer comparisons are sensitive to hidden bias in the regional analyses (Tables 7, 8) compared to the pooled sample (Table 6). However, it is mostly the non-statistically significant comparisons that are sensitive to bias. We reiterate here that low levels of sensitivity do not necessarily authenticate a study neither does high sensitivity intimate a faulty study (Sect. 3.2.2).

5 Discussion

5.1 Synthesis of findings

Overall, our results suggest that the exposure to this intervention focused on the promotion of BMPs and improved human nutrition through the provision of materials, training

Table 8 Propensity Score Matching (PSM) analysis for Shan state

Impact category	Variable	Groups (Observations (after common support)	Treatment effect (ATT)	Rosenbaum bounds gamma
Productivity	**Yield (kg/acre)**	1Y Beneficiaries vs Control	94.08 (66.76)	1.0#
		2Y Beneficiaries vs Control	185.28*** (44.55)	4.5
		2Y Beneficiaries vs 1Y Beneficiaries	108.57 (85.05)	2.7
	Total fish harvested (kg)	1Y Beneficiaries vs Control	-17.46* (8.56)	4.0
		2Y Beneficiaries vs Control	23.37* (13.30)	1.6
		2Y Beneficiaries vs 1Y Beneficiaries	47.13***(10.96)	7.3
Livelihoods	**Total fish revenue (1000MMK)**	1Y Beneficiaries vs Control	-54.97*** (18.27)	4.0
		2Y Beneficiaries vs Control	-8.36 (25.79)	-#
		2Y Beneficiaries vs 1Y Beneficiaries	66.78*** (23.96)	4.8
	Fish revenue per unit area (1000MMK/ acre)	1Y Beneficiaries vs Control	102.66 (109.56)	-#
		2Y Beneficiaries vs Control	232.76** (93.23)	1.4
		2Y Beneficiaries vs 1Y Beneficiaries	196.86 (146.19)	2.3
	Total household income (1000MMK)	1Y Beneficiaries vs Control	407,230 (344,958.30)	-#
		2Y Beneficiaries vs Control	1270.78*** (468.49)	2.5
		2Y Beneficiaries vs 1Y Beneficiaries	10,103.96** (471.058)	2.3
Food security	**Fish consumption (kg/week)**	1Y Beneficiaries vs Control	0.17 (0.39)	-#
		2Y Beneficiaries vs Control	1.11** (0.45)	1.5
		2Y Beneficiaries vs 1Y Beneficiaries	0.84 (0.80)	2.0
	Diet diversity (FCS score)	1Y Beneficiaries vs Control	28.73*** (4.42)	19.0
		2Y Beneficiaries vs Control	31.39*** (4.69)	16.0
		2Y Beneficiaries vs 1Y Beneficiaries	8.72** (3.48)	2.1

Parentheses in ATT column denote the standard error; Parentheses in the group column denote the final sample for each group after common support. "#" in the sensitivity analysis column indicate comparisons with low gamma scores that are indications of possible indication to hidden bias. Source: MYSAP endline survey data (2021)

*p < 0.10; **p < 0.05; *** p < 0.01

and extension had a largely positive effect on the productivity, livelihoods and food security of beneficiary households. However, this effect was mostly visible for the 2Y Beneficiaries whose performance for most impact variables was significantly better compared to households receiving just one year of intervention, or non-beneficiary households.

Similar findings have been found before for aquaculture interventions promoting improved production practices and nutrition to small-scale producers in Myanmar (see Karim et al., 2020; Belton et al., 2017) and other parts of southeast and south Asia (Dam Lam et al., 2022; N'souvi et al., 2021). However, we note that beyond the provision of effective support services for aquaculture production, such impacts are also mediated by other factors such as the prevalence of appropriate water resources for aquaculture and local familiarity and experience with aquaculture production (Filipski & Belton, 2018).

Figure 4 summarizes the observed trends for the different impact indicators for each group comparison, which are discussed in greater detail below.

In terms of productivity, although 1Y Beneficiaries in the Sagaing region and for the pooled data had higher adoption of BMPs and exposure to support services compared to Control producers (Table 4), this did not result in increased yields (actually it was associated with lower yields) (Tables 6 and 7). Conversely, for these samples 2Y Beneficiaries had significant higher yields compared to the Control farmers. Different observations came from the Shan region in that intervention beneficiaries reported almost immediate increases in yield compared to Control producers by year 1 (though insignificant), but by year 2 they had achieved a significantly higher yield (Table 8). These patterns are also present for the total amount of fish harvested, in that 1Y Beneficiaries harvest lower amounts than Control groups, but by the second year 2Y Beneficiaries either closed the production gaps (Tables 6–8),[7] or overtook the Control producers (Table 8). Such gains in yields and other productivity metrics have also been identified elsewhere for aquaculture after adoption of BMPs (Aung et al., 2023; Karim et al., 2020; N'souvi et al., 2021), and improvement in the access to critical resources

[7] These patterns for total fish harvest are expected to some degree as Control producers in Shan region have much larger ponds than both 1Y and 2Y Beneficiaries (Table 4).
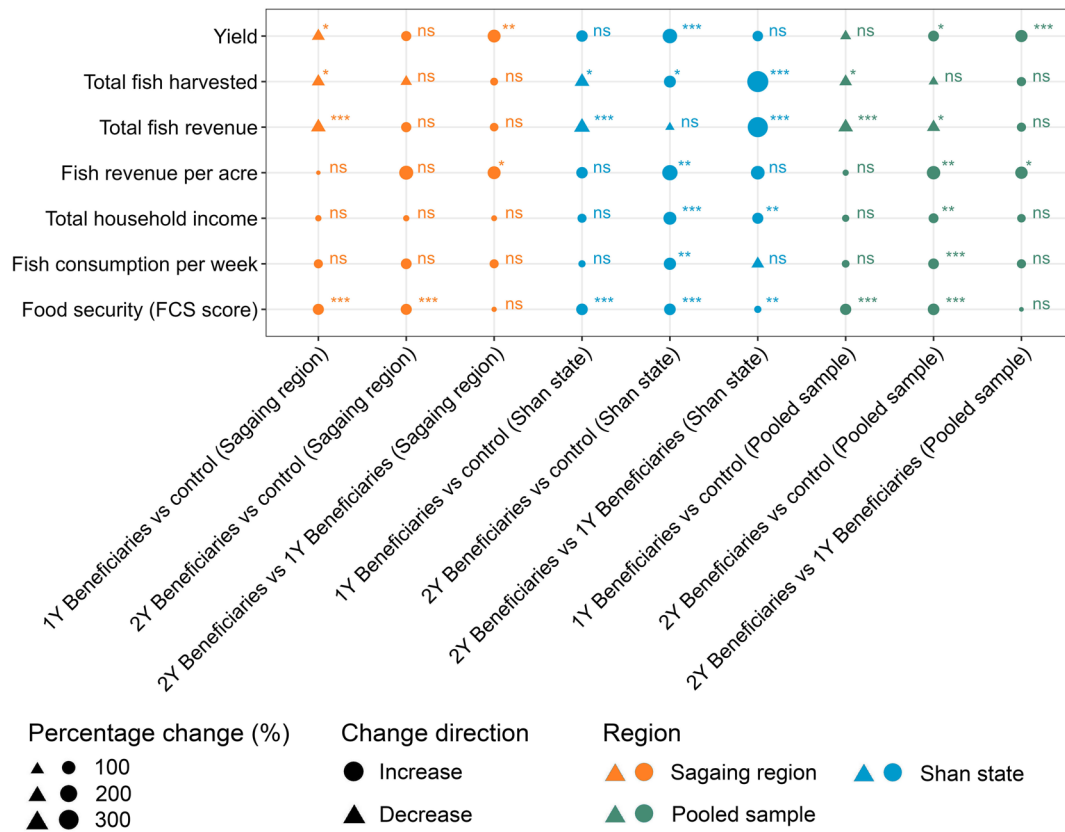
Fig. 4 Summary of aquaculture intervention impacts by study site and group comparison

(Amankwah & Quagrainie, 2019) and training (Dam Lam et al., 2022), all of which were integral components of the study intervention. This positive effect of improved technology adoption on productivity and yields has been also observed in very diverse smallholder contexts beyond aquaculture (Dompreh et al., 2021b; Kolapo & Kolapo, 2021; Kumar et al., 2020; Obiero et al., 2019). In general, we would expect this because farmers exposed to improved technologies and support services, increase their capacity to utilize effectively production inputs, and avoid wastage and practices that could stifle pond productivity (Murshed-E-Jahan & Pemsl, 2011; Barrett et al., 2021).

However, it is not clear why the improved productivity occurs by year 2 and not immediately, and whether it will be sustained. For the former, we hypothesise that it might be because 1Y Beneficiaries generally have lower aquaculture experience (Table 4) prior to their exposure to the intervention or that it took some time to get used to the proper implementation of the BMPs. Although it is as yet unknown whether these productivity gains can be sustained into the long term, our findings are encouraging considering that the probability of adopting agricultural technologies generally increases with the number of years technologies are exposed to farmers (Yigezu et al., 2018). Such longer production

experience allows farmers to appreciate the intricacies of agriculture/aquaculture technologies, enabling them to practice and improve their use over time (Ainembabazi & Mugisha, 2014).

For the livelihood variables, beneficiary farmers in both regions and the pooled sample generally improved their total household income and fish revenue per unit area (Tables 6–8). In most cases the results were statistically significant, and increase with a longer exposure to the interventions, as shown by the consistently higher performance for these indicators among 2Y Beneficiaries compared to 1Y Beneficiaries. Conversely, and similar to some productivity outcomes discussed above, although the total fish revenue was on average lower for beneficiaries compared to Control producers for most comparisons (Table 5), the PSM estimation shows a closing of the gaps with the Control producers for 2Y Beneficiaries (Tables 6–8). These results reflect the generally positive, but often differentiated, livelihood outcomes of exposure to aquaculture interventions (Karim et al., 2020; N'souvi et al., 2021; Filipski & Belton, 2018). For example, Karim et al. (2020) found that the introduction of improved aquaculture technologies increased farm productivities although with differentiated outcomes based on farmer location. Similarly, N'souvi et al. (2021) found

that aquaculture technologies enhance the production and profitability of aquaculture enterprises.

Similar to productivity, it is not clear why we also observe for livelihoods such differentiation between groups and impact variables, and particularly lower performance of 1Y beneficiaries. We believe that this partly relates to the generally larger pond sizes of Control producers (Table 4), resulting in more fish production for them and as a result for total fish revenue. However, the relatively similar total fish revenue per unit area of 1Y Beneficiaries compared to controls may be attributed to their comparatively low experience with the adopted BMPs as discussed earlier for productivity impacts, which can manifest in lower overall pond output and thus lower fish revenue (Obiero et al., 2019).

For food security, results from the regional and pooled analyses suggest that exposure to the intervention has divergent effects for the two variables we employed. The effect on weekly fish consumption was inconclusive, while the effect on diet diversity was significantly positive (Fig. 4). Notably the greater dietary diversity was stronger for 2Y Beneficiaries (Tables 6–8). Below we offer some possible explanations about these divergent patterns.

First, the small and often insignificant effect of exposure to the intervention on weekly fish consumption for Y1 Beneficiaries seems different from other small-scale aquaculture contexts that have recorded strong positive effects for fish self-consumption (e.g. Dam Lam et al., 2022 One possible explanation might be that by increasing their fish production and productivity, these beneficiary households tend to orient more towards market selling as evidenced by their generally higher revenue per unit area and total household income. This means that any fish productivity gains accruing from exposure to the intervention seem to be channeled towards external markets rather than household self-consumption, at least for 1Y Beneficiaries. In any case all groups record generally average levels of fish self-consumption ranging between roughly between 1.5 and 3 kg/week/household, which suggests that fish is not the main food item (Table 5).

Second, there are three possible and partly overlapping explanations about the observed improvements in dietary diversity, namely food purchases, crop diversity, and nutrition awareness. Regarding food purchase, as outlined in the previous paragraph, beneficiary households generally improved both their total income and aquaculture income per unit area (see also Ntiri et al., 2022; Filipski & Belton, 2018; Karim et al., 2020), which essentially increases their ability to purchase a diversity of food options, as has been identified in other contexts (Kassam, 2014). Regarding crop diversity, a key element of the intervention was to provide seeds of different crop species to promote food production in pond dykes and home gardens (Sect. 2). The effective implementation of this integrated aquaculture-crop production model has been generally associated with improved dietary diversity in small-scale aquaculture systems (Karim & Little, 2018). Regarding nutrition, the intervention contained a strong training element on the nutritional benefits of eating a diverse diet (Sect. 2).

These food security outcomes resonate with studies suggesting that exposure to small-scale integrated aquaculture interventions can enhance aspects of food security among producers (Kassam, 2014; Aung et al., 2023; Dam Lam et al., 2022). Arguably, such positive food security outcomes can be leveraged through diversified training, which beyond putting an emphasis on fish self-consumption or the consumption of diverse foods, also contains elements of healthy cooking and recipes to further improve the variety and utilization of food consumed in households (El Bilbeisi et al., 2022; Mortazavi et al., 2021).

Beyond these impacts, it is also important to note that the adoption of BMPs can have important ramifications for the intensification of small-scale aquaculture systems (Wang et al., 2023; Boyd et al., 2022; Schuur et al., 2022). In many group comparisons we find significant gains in yields and income generation from aquaculture for beneficiary groups, which are both strong indications of intensification. Although the intensification outcomes were not the focus of our study, such shifts can have ramifications for the environmental footprint of aquaculture production systems (Boyd et al., 2022; Wang et al., 2023). Such studies are missing in Myanmar (Wang et al., 2023), and are a major knowledge gap that future work should seek to address.

5.2 Linking positive outcomes to intervention exposure and sustained adoption

One recurring theme in our analysis is that 2Y Beneficiaries have higher BMP adoption and performed better for practically all impact variables compared to 1Y Beneficiaries and Control groups, with most of the results being statistically significant (Tables 5–8, Figs. 3, 4). Considering that 2Y and 1Y Beneficiaries received exactly the same support, when explaining this pattern we should remember that the frequency of extension contact generally facilitates the better adoption/implementation of agriculture/aquaculture technologies (Adeoti et al., 2009; Kumar et al., 2018; Ragasa et al., 2013) and that technology adoption is a dynamic process requiring time, training and a conducive system (Aramburu et al., 2019; Jones-Garcia & Krishna, 2021; Karim et al., 2020; Kumar et al., 2018; Oyetunde-Usman, 2022). Considering these we believe that the better performance is due to 2Y Beneficiaries' longer-term access to critical knowledge through 'learning-by-doing and learning from others' (Caeiro, 2019; Foster & Rosenzweig, 1995), and access to extension support as part of a conducive system (Aung et al., 2023; Karim et al., 2020).

First, the intervention made a strong effort to organize farmers in groups, and create a collaborative and mutual learning environment within groups. After the end of an intervention, producers may not have achieved a perfect capability to implement the agricultural technology (aquaculture BMPs in this case). However, through continuous practice they can improve considerably their skills and confidence in implementing the knowledge gained (Murshed-E-Jahan & Pemsl, 2011). More importantly longer engagement with farmer groups through demonstration ponds and neighbor's ponds can assist farmers to improve their knowledge through mutual support, under the assumption that individuals learn from neighbors, friends and peers, partly influenced by social pressure and mimicking of good behaviour (Foster & Rosenzweig, 1995).

Second, generally the intervention offered a comprehensive extension package in a country with few and low capacity aquaculture extension officers in public institutions (Karim et al., 2020), inability of poor farmers to access such services, and a political climate that often constrains the work of international organizations (Stokke et al., 2018). As shown in Table 4, the 2Y and 1Y Beneficiaries were exposed substantially more times to extension services and related support than Control producers. This likely improved their capacity to implement the BMPs (Joffre et al., 2017; Kumar et al., 2018), as several studies show that the frequency of exposure to extension enhances the adoption and impact of agriculture/aquaculture technologies (Feyisa, 2020; Masresha et al., 2017; Simtowe et al., 2011; Yigezu et al., 2018).

Finally, we note the relative parity in the gender of the household head for 2Y Beneficiary households (particularly in the Shan state) compared to the much more male-dominate control groups (Table 4). This is an optimistic sign for gender empowerment and livelihood benefits to female-headed households, especially when considering their generally lower and more unequal engagement in aquaculture activities and value chains (De & Pandey, 2014; Kruijssen et al., 2018.

5.3 Implications and recommendations

Given the short term assessment we report here, we hope the gains made in terms of productivity, livelihoods and food security can be sustained following the conclusion of interventions in the absence of a conducive aquaculture system, but there could be a relapse to small-scale systems characterized by low productivity and lack of access to inputs/information (Filipski & Belton, 2018; Karim et al., 2020). Avoiding relapses would require concerted efforts to sustain the adoption and proper implementation of small-scale aquaculture BMPs, via a conducive environment that facilitates access to high quality inputs (e.g., fish seed, feed) and relevant information. Effective and continuous

extension support to small-scale producers should be a central element of building such a conducive small-scale aquaculture environment, in Myanmar and other developing contexts. Two possible pathways to achieve this are (a) establishing effective collaboration between private and public institutions for extension service delivery, and (b) facilitating even stronger bonds between small-scale producers through farmer-led organizations.

Regarding (a), the delivery of extension services is a key challenge for the aquaculture sector, both in Myanmar and elsewhere (Aung et al., 2023; Karim et al., 2020; N'souvi et al., 2021). Even with major aquaculture production hubs, extension services are often absent (CGIAR, 2018). This is particularly evident in Myanmar, where the national government has identified the improvement and enhancement of extension service delivery as a strategic area for boosting rural development (MoALI & MAFF, 2017). However, these commitments are yet to materialize as extension agents are practically non-existent even in major aquaculture production hubs (Karim et al., 2020; CGIAR, 2018). It might be possible to facilitate the longer-term provision of extension services through the closer cooperation of public institutions with private entities such as NGOs and private businesses (Aung et al., 2023; N'souvi et al., 2021). As different studies around the world have shown this will likely require context-specific paradigm shifts in how extension is provided or even how small-scale production systems and markets operate (Aung et al., 2023; Girma & Kuma, 2022; Labarthe & Laurent, 2013; Ntiri et al., 2022), especially in a country like Myanmar where the government plays a strong role in most aspects of the economy.

With (b), in the possible absence of long-term extension services, there could be efforts during the initial intervention to organize farmers into well-structured producer groups. The establishment of producer groups can have a positive impact on the sustained adoption of improved technologies through motivation, shared risk management, trust, economies of scale on input purchase and benefits from shared learning among farmers (Abdul-Rahaman & Abdulai, 2018; Joffre et al., 2020). Although the development of such groups is often an integral component of many relevant interventions (Dam Lam et al., 2022; Fenger et al., 2017), studies have shown that they usually stop operating properly following the end of interventions (De Prima et al., 2022; Hiller et al., 2016; ILO, 2017; Shilomboleni et al., 2019). By emphasizing during the early phases of interventions the need to ensure the long-term operation of producer-based organizations could facilitate the easier and quicker delivery of extension and shared learning (Joffre et al., 2020; Ntiri et al., 2022). Such groups can serve as effective platforms for continuous access to extension through the collective use of Information and Communication Technologies (ICT) for knowledge transfer (Ntiri et al., 2022).

6 Conclusion

In this study we analyzed through the Propensity Score Matching (PSM) approach data from 379 small-scale aquaculture producers in Myanmar, to assess the impact of exposure to an intervention that promoted Best Management Practices (BMPs) for aquaculture and nutrition-sensitive information for households through extension services. The focus was on seven impact variables that collectively reflected different aspects of pond productivity, livelihoods and food security. The results show that exposure to the aquaculture intervention had a generally positive effect for most impact variables, with variable effects, however, among some variables and group comparisons. In particular, in terms of food security while beneficiaries had significantly higher dietary diversity (measured as the Food Consumption Score, FCS), there were no significant differences for fish self-consumption (measured in kg/week). Longer exposure to and use of such interventions over two years produced significantly higher positive effects across almost all seven impact variables compared to 1-year beneficiaries and control groups.

From these results we suggest that relevant stakeholders should actively consider how to facilitate effective and consistent delivery of long-term extension services to small-scale aquaculture producers in Myanmar. Creating a conducive aquaculture system could prevent the return to small-scale systems characterized by low productivity and lack of access to inputs and information following the end of aquaculture interventions. This might require novel ways of extension delivery in the long-term but could certainly contribute significantly to many relevant rural development goals in Myanmar and beyond, including reducing poverty, achieving zero hunger, and providing decent work and economic growth, all of which are significant aspects of the Sustainable Development Goals (SDGs).

Declarations

References

Abdul-Rahaman, A., & Abdulai, A. (2018). Do farmer groups impact on farm yield and efficiency of smallholder farmers? *Evidence from Rice Farmers in Northern Ghana, Food Policy, 81*, 95–105. https://doi.org/10.1016/j.foodpol.2018.10.007

Adeoti, A., Barry, B., Namara, R., & Kamara, A. (2009). The impact of treadle pump irrigation technology adoption on poverty in Ghana. *The Journal of Agricultural Education and Extension, 15*(4), 357–369. https://doi.org/10.1080/13892240903309611

Ahmed, A., Dompreh, E. B., & Gasparatos, A. (2019). Human well-being outcomes of involvement in industrial crop production in Ghana: Evidence from sugarcane, oil palm and jatropha sites. *PLoS ONE, 14*(4), e0215433. https://doi.org/10.1371/journal.pone.0215433

Ahmed, B. N., & Waibel, H. (2019). The role of homestead fish ponds for household nutrition security in Bangladesh. *Food Security, 11*(4), 835–854. https://doi.org/10.1007/s12571-019-00947-6

Ainembabazi, J. H., & Mugisha, J. (2014). The Role of Farming Experience on the Adoption of Agricultural Technologies: Evidence from Smallholder Farmers in Uganda. *The Journal of Development Studies, 50*(5), 666–679. https://doi.org/10.1080/00220388.2013.874556

Amankwah, A., & Quagrainie, K. K. (2019). Aquaculture feed technology adoption and smallholder household welfare in Ghana. *Journal of the World Aquaculture Society, 50*(4), 827–841. https://doi.org/10.1111/jwas.12544

Apiors, E. K., & Suzuki, A. (2018). Mobile money, individuals' payments, remittances, and investments: Evidence from the Ashanti Region. *Ghana. Sustainability, 10*(5), 1–26. https://doi.org/10.3390/su10051409

Aramburu, J., Garone, L. F., Maffioli, A. Salazar, L. & Lopez, C. A. (2019). Direct and spillover effects of agricultural technology adoption programs: Experimental evidence from the Dominican Republic. IDB Working Paper Series No. IDB-WP-00971, Environment, Rural Development and Disaster Risk Management, Division Inter-American Development Bank.

Aregu, L., Rajaratnam, S., Mcdougall, C., Johnstone, G., Wah, Z. Z., New, K. M., Akester, M., Grantham, R. & Karim, M. (2017). Gender in Myanmar's small-scale aquaculture sector. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems. Program Brief: Fish-2017–12.

Armijo-Olivo, S., Mohamad, N., de Oliveira-Souza, A. I. S., de Castro-Carletti, E. M., Ballenberger, N. & Fuentes, J. (2022). Performance, Detection, Contamination, Compliance, and Cointervention Biases in Rehabilitation Research. What Are They and How Can They Affect the Results of Randomized Controlled Trials? Basic Information for Junior Researchers and Clinicians. *American Journal of Physical Medicine & Rehabilitation, 101*(9), 864–878.

Aung, Y. M., Khor, L. Y., Tran, N., Akester, M., & Zeller, M. (2023). The impact of sustainable aquaculture technologies on the welfare of small-scale fish farming households in Myanmar. *Aquaculture Economics & Management, 27*, 66–95. https://doi.org/10.1080/13657305.2021.2011988

Aweke, C. S., Hassen, J. Y., Wordofa, M. G., Moges, D. K., Endris, G. S., & Rorisa, D. T. (2021). Impact assessment of agricultural technologies on household food consumption and dietary diversity in Eastern Ethiopia. *Journal of Agriculture and Food Research, 4*, 100141.

Ayalew, A. Z., Bethelhem, L. D. & Menale, K. (2019). The joint impact of improved maize seeds on productivity and efficiency: Implications for policy, GlobalFood Discussion Papers, No. 128, Georg-August-Universität Göttingen, Research Training Group (RTG) 1666 - GlobalFood, Göttingen.

Azra, M. N., Okomoda, V. T., Tabatabaei, M., Hassan, M., & Ikhwanuddin, M. (2021). The Contributions of Shellfish Aquaculture to Global Food Security: Assessing its Characteristics from a Future Food Perspective. *Frontiers in Marine Science, 8*, 654897. https://doi.org/10.3389/fmars.2021.654897

Bambio, Y., Deb, A. & Kazianga, H. (2022). Exposure to agricultural technologies and adoption: The West Africa agricultural productivity program in Ghana, Senegal and Mali. *Food Policy,* 102288. https://doi.org/10.1016/j.foodpol.2022.102288

Bareinboim, E., & Pearl, J. (2012). Controlling Selection Bias in Causal Inference. *JMLR Proceedings of the Fifteenth International Conference on Artificial Intelligence and Statistics (AISTATS), 22*, 100–108.

Barrett, C. B., Islam, A., Malek, A. M., Pakrashi, D., & Ruthbah, U. (2021). Experimental evidence on adoption and impact of the System of Rice Intensification. *American Journal of Agricultural Economics, 104*, 4–32. https://doi.org/10.1111/Ajae.12245

Belton, B., Hein, A., Htoo, K., Kham, L. S., Phyoe, A. S., & Reardon, T. (2018). The emerging quiet revolution in Myanmar's aquaculture value chain. *Aquaculture, 493*, 384–394. https://doi.org/10.1016/j.aquaculture.2017.06.028

Belton, B., Filipski, M. & Hu, C. (2017). Aquaculture in Myanmar: Fish farm technology, production economics and management. Feed the Future Innovation Lab for Food Security Policy. Food Security Policy Project (FSPP). Research Paper 52. http://Ebrary.Ifpri.Org/Utils/Getfile/Collection/P15738coll2/Id/132424/Filename/132632.Pdf

Belton, B., Hein, A., Htoo, K., Seng Kham, L., Nischan, U., Reardon, T., & Boughton, D. (2015). Aquaculture in transition: Value chain transformation, fish and food security in Myanmar. Vol. 1. https://doi.org/10.1017/Cbo9781107415324.004.

Bernzen, A., Mangnus, E., & Sohns, F. (2022). Diversify, produce or buy? An analysis of factors contributing to household dietary diversity among shrimp and non-shrimp farmers in coastal Bangladesh. *Food Security, 14*(3), 741–761. https://doi.org/10.1007/s12571-021-01245-w

Bondad-Reantaso, M. G. & Prein, M. (2009). Measuring the contribution of small-scale aquaculture: An assessment. FAO Fisheries and Aquaculture Technical Paper. No. 534. Rome, FAO. 2009. 180p. https://doi.org/10.13140/RG.2.1.3837.3841

Bone, J., Clavelle, T., Ferreira, J. G., Grant, J., Ladner, I., Immink, A., Stoner, J. & Taylor, N. G. H. (2018). Best Practices for Aquaculture Management Guidance for implementing the ecosystem approach in Indonesia and beyond. https://www.fao.org/flw-in-fish-value-chains/flw-in-fish-value-chainsresources/resources/best-practices-for-aquaculture-management/best-practices-for-aquaculture-management/ru/

Boyd, C. E., Davis, R. P., & McNevin, A. A. (2022). Perspectives on the mangrove conundrum, land use, and benefits of yield intensification in farmed shrimp production: A review. *Journal of World Aquaculture Society, 53*, 8–46.

Bush, S. R., Pauwelussen, A., Badia, P., Kruk, S., Little, D., Luong, L. T., Newton, R., Nhan, D. T., Rahman, M. M., Sorgeloos, P., & YikSung, Y. (2021). Implementing aquaculture technology and innovation platforms in Asia. *Aquaculture, 530*, 735822.

Caeiro, M. (2019). From Learning to Doing: Diffusion of agricultural innovations in Guinea-Bissau. Rute NBER Working Paper No. 26065. http://www.nber.org/papers/w26065

Caliendo, M., & Kopeinig, B. S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys, 22*(1), 31–72. https://doi.org/10.1111/j.1467-6419.2007.00527.x

Central Statistical Organization, UNDP, & World Bank. (2019). Myanmar living conditions survey 2017 poverty report. Report 3. https://documents1.worldbank.org/curated/en/921021561058201854/pdf/Myanmar-Living-Condition-Survey-2017-Report-3-Poverty-Report.pdf

CGIAR Research Program on Fish Agri-Food Systems. (2018). Myanmar Fisheries and Aquaculture Research Symposium Proceedings. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems. Proceedings: FISH-2018–03.

Cheema, A. R., Mehmood, A., & Khan, F. A. (2018). Challenges of research in rural poverty: Lessons from large field surveys. *Development in Practice, 28*(5), 714–719. https://doi.org/10.1080/09614524.2018.1467881

Dam Lam, R., Barman, B. K., Lozano, D., Khatun, Z., Parvin, L., Choudhury, A., Rossignoli, C., Karanja, A., & Gasparatos, A. (2022). Sustainability impacts of ecosystem approaches to small-scale aquaculture in Bangladesh. *Sustainability Science, 17*, 295–313.

De, H. K., & Pandey, D. K. (2014). Constraints to Women's Involvement in Small Scale Aquaculture: An exploratory study. *International Journal of Agricultural Extension, 2*(1), 81–88.

Dehejia, R. H., & Wahba, S. (2002). Propensity score matching methods for non-experimental causal studies. *Revue of Economics and Statistics, 84*, 151–161.

Di Prima, S., Wright, E. P., Sharma, I. K., Syurina, E., & Broerse, J. E. W. (2022). Implementation and scale-up of nutrition-sensitive agriculture in low- and middle-income countries: A systematic review of what works, what doesn't work and why. *Global Food Security, 32*, 100595. https://doi.org/10.1016/j.gfs.2021.100595

Dompreh, E. B., Asare, R., & Gasparatos, A. (2021a). Do voluntary certification standards improve yields and wellbeing? Evidence from oil palm and cocoa smallholders in Ghana. *International Journal of Agricultural Sustainability, 19*, 16–39.

Dompreh, E. B., Asare, R., & Gasparatos, A. (2021b). Sustainable but hungry? Food security outcomes of certification for cocoa and oil palm smallholders in Ghana. *Environmental Research Letters, 16*, 055001.

El Bilbeisi, A. H., Al-Jawaldeh, A., Albelbeisi, A., Abuzerr, S., Elmadfa, I., & Nasreddine, L. (2022). Households' Food Insecurity and their Association with Dietary Intakes, Nutrition-Related Knowledge, Attitudes and Practices Among Under-five Children in Gaza Strip. *Palestine. Frontiers in Public Health, 10*, 808700. https://doi.org/10.3389/fpubh.2022.808700

Etuk, E. A., & Ayuk, J. O. (2021). Agricultural commercialisation, poverty reduction and pro-poor growth: Evidence from commercial agricultural development project in Nigeria. *Heliyon, 7*(5), e06818.

FAO. (2020a). FAO Yearbook. Fishery and Aquaculture Statistics 2018/FAO Annuaire. Statistiques Des Pêches Et De L'aquaculture 2018/Fao Anuario. Estadísticas De Pesca Y Acuicultura 2018. Rome. https://doi.org/10.4060/Cb1213t

FAO. (2020b). *The State of World Fisheries and Aquaculture 2020*. Sustainability in Action. https://doi.org/10.4060/Ca9229en

Fenger, N. A., Bosselmann, A. S., Asare, R., & de Neergaard, A. (2017). The impact of certification on the natural and financial capitals of Ghanaian cocoa farmers. *Agroecology and Sustainable Food Systems, 41*, 143–166.

Feyisa, B. W. (2020). Determinants of agricultural technology adoption in Ethiopia: A meta-analysis. *Cogent Food & Agriculture, 6*, 1. https://doi.org/10.1080/23311932.2020.1855817

Filipski, M., & Belton, B. (2018). Give a man a fishpond: Modeling the impacts of aquaculture in the Rural Economy. *World Development, 110*, 205–223. https://doi.org/10.1016/j.worlddev.2018.05.023

Foster, A. D. & Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of Political Economy, 103*(6). https://doi.org/10.1086/601447

Froehlich, A. G., Melo, A. S. S. A., & Sampaio, B. (2018). Comparing the profitability of Organic and Conventional production in family farming: Empirical evidence from Brazil. *Ecological Economics, 150*, 307–314.

Garlock, T., Asche, F., Anderson, J., Ceballos-Concha, A., Love, D. C., Osmundsen, T. C., & Pincinato, R. B. M. (2022). Aquaculture: The missing contributor in the food security agenda. *Global Food Security, 32*, 100620. https://doi.org/10.1016/j.gfs.2022.100620

Gasparatos, A., Mudombi, S., Balde, B., von Maltitz, G., Johnson, F. X., Romeu-Dalmau, C., Jumbe, C., Ochieng, C., et al. (2022). Local food security impacts of biofuel crop production in southern Africa. *Renewable and Sustainable Energy Reviews, 154*, 111875.

Giri, S. S. (Ed.). (2017). *Best Management Practices in Aquaculture: Capacity Building and Policy Development* (p. 154p). SAARC Agriculture Centre.

Girma, Y., & Kuma, B. (2022). A meta analysis on the effect of agricultural extension on farmers' market participation in Ethiopia. *Journal of Agriculture and Food Research, 7*, 100253. https://doi.org/10.1016/j.jafr.2021.100253

Habtewold, T. M. (2021). Impact of climate-smart agricultural technology on Multidimensional Poverty in rural Ethiopia. *Journal of Integrative Agriculture, 20*(4), 1021–1041.

Hasebe, T. (2020). Endogenous switching regression model and treatment effects of count-data outcome. *The Stata Journal, 20*(3), 627–646. https://doi.org/10.1177/1536867X20953573

Hendriks, S. L. (2015). The food security continuum: A novel tool for understanding food insecurity as a range of experiences. *Food Security, 7*, 609–619. https://doi.org/10.1007/s12571-015-0457-6

Hernan, M. A., Hernandez-Dıaz, S., & Robins, J. M. (2004). A Structural Approach to Selection Bias. *Epidemiology, 15*(5), 615–625.

Hiller, B. T., Guthrie, P. M., & Jones, A. W. (2016). Overcoming Ex-Post Development Stagnation: Interventions with Continuity and Scaling in Mind. *Sustainability, 8*, 155. https://doi.org/10.3390/su8020155

Hirano, K., & Imbens, G. (2001). Estimation of causal effects using propensity score weighting: An application to data on right heart catherization. *Health Services and Outcomes Research Methodology, 2*, 259–278. https://doi.org/10.1023/A:1020371312283

Howerton, R. (2001). Best management practices for Hawaiian aquaculture. *Center for Tropical and Subtropical Aquaculture Publication No. 148*. http://www.ctsa.org/files/publications/CTSA_148631672853284080260.pdf

ILO. (2017). Improving market access for smallholder farmers: What works in out-grower schemes – evidence from Timor-Leste. Issue Brief No 1, March 2017. https://www.ilo.org/wcmsp5/groups/public/---ed_emp/---emp_ent/documents/publication/wcms_547157.pdf

Irwin, S., Flaherty, M. S., & Carolsfeld, J. (2021). The contribution of small-scale, privately owned tropical aquaculture to food security and dietary diversity in Bolivia. *Food Security, 13*(1), 199–218. https://doi.org/10.1007/s12571-020-01104-0

Islam, A. H. M. S., Barman, B. K., & Murshed-E-Jahan, K. (2015). Adoption and impact of integrated rice–fish farming system in Bangladesh. *Aquaculture, 447*, 76–85. https://doi.org/10.1016/j.aquaculture.2015.01.006

Jalan, J., & Ravallion, M. (2003). Does piped water reduce diarrhea for children in rural India? *Journal of Econometrics, 112*, 153–173.

Joffre, O. M., De Vries, J. R., Klerkx, L., & Poortvliet, P. M. (2020). Why are cluster farmers adopting more aquaculture technologies and practices? The role of trust and interaction within shrimp farmers' networks in the Mekong Delta. *Vietnam. Aquaculture, 523*, 735181. https://doi.org/10.1016/j.aquaculture.2020.735181

Joffre, O. M., Klerkx, L., Dickson, M., & Verdegem, M. (2017). How is innovation in aquaculture conceptualized and managed? A systematic literature review and reflection framework to inform analysis and action. *Aquaculture, 470*, 129–148.

Jones-Garcia, E., & Krishna, V. V. (2021). Farmer adoption of sustainable intensification technologies in the maize systems of the Global South. *A Review. Agronomy for Sustainable Development, 41*, 8. https://doi.org/10.1007/s13593-020-00658-9

Karim, M., Leemans, K., Akester, M., & Phillips, M. (2020). Performance of emergent aquaculture technologies in Myanmar. *Challenges and Opportunities. Aquaculture, 519*, 734875.

Karim, M., & Little, D. C. (2018). The impacts of integrated homestead pond-dike systems in relation to production, consumption and seasonality in central north Bangladesh. *Aquaculture Research, 49*, 313–334. https://doi.org/10.1111/are.13462

Kassam, L. (2014). Aquaculture and food security, poverty alleviation and nutrition in Ghana: Case study prepared for the Aquaculture for Food Security, Poverty Alleviation and Nutrition project. WorldFish, Penang, Malaysia. Project Report: 2014–48.

Khandker, S. R., & Koolwal, G. B. (2016). How has microcredit supported agriculture? Evidence using panel data from Bangladesh. *Agricultural Economics, 47*, 157–168. https://doi.org/10.1111/agec.12185

Kolapo, A., & Kolapo, A. J. (2021). Welfare and productivity impact of adoption of biofortified cassava by smallholder farmers in Nigeria. *Cogent Food & Agriculture, 7*, 1. https://doi.org/10.1080/23311932.2021.1886662

Kruijssen, F., McDougall, C. L., & van Asseldonk, I. J. M. (2018). Gender and aquaculture value chains: A review of key issues and implications for research. *Aquaculture, 493*, 328–337. https://doi.org/10.1016/j.aquaculture.2017.12.038

Kumar, A., Takeshima, H., Thapa, G., Adhikari, N., Saroj, S., Karkee, M., & Joshi, P. K. (2020). Adoption and diffusion of improved technologies and production practices in agriculture: Insights from a donor-led intervention in Nepal. *Land Use Policy, 95*, 104621.

Kumar, G., Engle, C., & Tucker, C. (2018). Factors driving aquaculture technology adoption. *Journal of World Aquaculture Society, 49*(3), 447–476. https://doi.org/10.1111/jwas.12514

Labarthe, P., & Laurent, C. (2013). Privatization of agricultural extension services in the EU: Towards a lack of adequate knowledge for small-scale farms? *Food Policy, 38*, 240–252. https://doi.org/10.1016/j.foodpol.2012.10.005

Makate, C., Makate, M., Mutenje, M., Mango, N., & Siziba, S. (2019). Synergistic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in southern Africa. *Environmental Development, 32*, 100458.

Main, B. G. M., & Reilly, B. (1993). The employer size–wage gap: Evidence for Britain. *Economica, 60*, 125–142.

Martens, E. P., Pestman, W. R., de Boer, A., Belitser, S. V., & Klungel, O. H. (2006). Instrumental variables: Application and limitations. *Epidemiology, 17*(3), 260–267. https://doi.org/10.1097/01.ede.0000215160.88317.cb

Masresha, D., Legesse, B., Haji, J., & Zemedu, L. (2017). Determinants of the adoption of improved white haricot beans in east Shewa zone, south-eastern Ethiopia. *Journal of Development and Agricultural Economics, 9*(12), 355–372. https://doi.org/10.5897/JDAE2017.0860

Mendola, M. (2007). Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy, 32*, 372–393.

Merino, G., Barange, M., Blanchard, J. L., Harle, J., Holmes, R., Allen, I., Allison, E. H., et al. (2012). Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? *Global Environmental Change, 22*(4).

Mitiku, F., de Mey, Y., Nyssen, J. & Maertens, M. (2017). Do private sustainability standards contribute to income growth and poverty alleviation? A comparison of different coffee certification schemes in Ethiopia. *Sustainability, 9*(2), 246. https://doi.org/10.3390/su9020246

MoALI & MAFF. (2017). Food Value Chain Road Map (2016–2020) in Myanmar. Ministry of Agriculture, Livestock and Irrigation, Myanmar and Ministry of Agriculture, Forestry and Fisheries, Japan. https://www.maff.go.jp/j/kokusai/kokkyo/attach/pdf/myanmar-3.pdf

Mortazavi, Z., Dorosty, A. R., Eshraghian, M. R., Ghaffari, M., & Ansari-Moghaddam, A. (2021). Nutritional Education and Its Effects on Household Food Insecurity in Southeastern Iran. *Iran Journal Public Health, 50*(4), 798–805. https://doi.org/10.18502/ijph.v50i4.6006

Mudombi, S., Ochieng, C., Johnson, F. X., von Maltitz, G., Luhanga, D., Dompreh, E. B., Romeu-Dalmau, C., & Gasparatos, A. (2021). Fuelling rural development? The impact of biofuel feedstock production in southern Africa on household income and expenditures. *Energy Research & Social Science, 76*, 102053. https://doi.org/10.1016/j.erss.2021.102053

Murshed-E-Jahan, K., & Pemsl, D. E. (2011). The Impact of Integrated Aquaculture-Agriculture on Small-Scale Farm sustainability and Farmers' Livelihoods: Experience from Bangladesh. *Agricultural Systems, 104*(5), 392–402.

Nakano, Y., & Magezi, E. F. (2020). The impact of microcredit on agricultural technology adoption and productivity: Evidence from

randomized control trial in Tanzania. *World Development, 133*, 104997. https://doi.org/10.1016/j.worlddev.2020.104997

Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., Little, D. C., et al. (2021). A 20-year retrospective review of global aquaculture. *Nature, 591*, 551–563. https://doi.org/10.1038/s41586-021-03308-6

N'souvi, K., Sun, C., & Che, B. (2021). Aquaculture technology adoption and profitability of the polyculture system practiced by prawn and crab farmers: Case study of Anhui province in China. *Aquaculture Reports, 21*, 100896.

Ntiri, P., Ragasa, C., Anang, S. A., Kuwornu, J. K. M., & Torbi, E. N. (2022). Does ICT-based aquaculture extension contribute to greater adoption of good management practices and improved incomes? *Evidence from Ghana. Aquaculture, 557*, 738350. https://doi.org/10.1016/j.aquaculture.2022.738350

Obiero, K. O., Waidbacher, H., Nyawanda, B. O., Munguti, J. M., Manyala, J. O., & Kaunda-Arara, B. (2019). Predicting uptake of aquaculture technologies among smallholder fish farmers in Kenya. *Aquaculture Int, 27*, 1689–1707. https://doi.org/10.1007/s10499-019-00423-0

Ojo, T. O., & Baiyegunhi, L. J. S. (2020). Impact of climate change adaptation strategies on rice productivity in South-west, Nigeria: An endogeneity corrected stochastic frontier model. *Science of the Total Environment, 745*, 141151. https://doi.org/10.1016/j.scitotenv.2020.141151

Olmos, A., & Govindasamy, P. (2015). Propensity scores: A practical introduction using R. *Journal of Multi Disciplary Evaluation, 11*, 68–88.

Oyetunde-Usman, Z. (2022). Heterogenous factors of adoption of agricultural technologies in West and East Africa countries: A review. *Frontiers in Sustainable Food Systems, 16*.

Paul, B. J., & Vogl, C. R. (2013). Organic shrimp aquaculture for sustainable household livelihoods in Bangladesh. *Ocean & Coastal Management, 71*, 1–12.

Pradeepkiran, J. A. (2019). Aquaculture role in global food security with nutritional value: A review. *Translational Animal Science, 3*(2), 903–910. https://doi.org/10.1093/tas/txz012

Ragasa, C., Amewu, S., Agyakwah, S. K., Mensah, E. T.-. D., & Asmah, R. (2022a). Impact of aquaculture training on farmers' income: Cluster randomized controlled trial evidence in Ghana. *Agricultural Economics, 53*, 5–20. https://doi.org/10.1111/agec.12754

Ragasa, C., Agyakwah, S. K., Asmah, R., Mensah, E. T.-D., Amewu, S., & Oyih, M. (2022b). Accelerating pond aquaculture development and resilience beyond COVID: Ensuring food and jobs in Ghana. *Aquaculture, 547*, 737476.

Ragasa, C., Berhane, G., Tadesse, F., & Taffesse, A. S. (2013). Gender differences in access to extension services and agricultural productivity. *The Journal of Agricultural Education and Extension, 19*(5), 437–468. https://doi.org/10.1080/1389224x.2013.817343

Rosenbaum, P. R. (2002). *Observational studies* (2nd ed.). Springer.

Rubin, D., & Thomas, D. (2000). Combining propensity score matching with additional adjustments for prognostic covariates. *Journal of the American Statistical Association, 95*, 573–585.

Schuur, A. M., McNevin, A. A., Davis, R. P., Boyd, C. E., Brian, S., Tinh, H. Q., & Duy, N. P. (2022). Technical and financial feasibility for intensification of the extensive shrimp farming area in Mekong Delta. *Vietnam. Aquaculture, Fish & Fisheries, 2*, 12–27.

Shilomboleni, H., Owaygen, M., De Plaen, R., Manchur, W., & Husak, L. (2019). Scaling up innovations in smallholder agriculture: Lessons from the Canadian international food security research fund. *Agricultural Systems, 175*, 58–65. https://doi.org/10.1016/j.agsy.2019.05.012

Simtowe, F., Kassie, M., Diagne, A., Asfaw, S., Shiferaw, B., Silim, S., & Muange, E. (2011). Determinants of Agricultural Technology Adoption: The Case of improved Pigeonpea varieties in Tanzania. *Quarterly Journal of International Agriculture, 50*(4), 325–345.

Stokke, K., Vakulchuk, R. & Øverland, I. (2018). Myanmar: A Political Economy Analysis. Report commissioned by the Norwegian Ministry of Foreign Affairs, Norwegian Institute of International Affairs. https://reliefweb.int/report/myanmar/myanmar-political-economy-analysis

Stuart, E. A. (2010). Matching methods for causal inference: A review and a look forward. *Statistical Science, 25*(1), 1–21. https://doi.org/10.1214/09-STS313

Tezzo, X., Belton, B., Johnstone, G., & Callow, M. (2018). Myanmar's fisheries in transition: Current status and opportunities for policy reform. *Marine Policy, 97*, 91–100.

Toufique, K. A., & Belton, B. (2014). Is Aquaculture Pro-Poor? Empirical Evidence of Impacts on Fish Consumption in Bangladesh. *World Development, 64*, 609–620. https://doi.org/10.1016/j.worlddev.2014.06.035

Tran, N., Lecao, Q., Shikuku, K. M., Phan, T. P., & Banks, L. K. (2020). Profitability and perceived resilience benefits of Integrated Shrimp-Tilapia-Seaweed aquaculture in North Central Coast. *Vietnam. Marine Policy, 120*, 104153.

van Duijn, A. P., van der Heijden, P. G. M., Bolman, B. & Rurangwa, E. (2018). Review and analysis of small-scale aquaculture production in East Africa; Summary and Recommendations. Wageningen Centre for Development Innovation, Wageningen University & Research. Report WCDI18–019. Wageningen.

Verbowski, V., Talukder, Z., Hou, K., Sok Hoing, L., Michaux, K., Anderson, V., Gibson, R., et al. (2018). Effect of enhanced homestead food production and aquaculture on dietary intakes of women and children in rural Cambodia: A cluster randomized controlled trial. *Maternal and Child Nutrition, 14*(3), e12581. https://doi.org/10.1111/mcn.12581

Waite, R., Beveridge, M., Brummett, R., Castine, S., Chaiyawannakarn, N., Kaushik, S., Mungkung, R., et al., (2014). Improving Productivity and Environmental Performance of Aquaculture. Working Paper, Installment 5 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute. Accessible at http://www.worldresourcesreport.org

Wang, Q., Rossignoli, C., Dompreh, E. B., Su, J., Ali, A., Karim, M., & Gasparatos, A. (2023). Sustainable intensification of small-scale aquaculture production in Myanmar through diversification and better management practices. *Environmental Research Letters, 18*, 015002.

Wessells, K. R., & Brown, K. H. (2012). Estimating the global prevalence of zinc deficiency: Results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS ONE, 7*(11), e50568. https://doi.org/10.1371/journal.pone.0050568

WFP. (2008). Food consumption analysis: calculation and use of the food consumption score in food security analysis Technical Guidance Sheet. https://documents.wfp.org/stellent/groups/public/documents/manual_guide_proced/wfp197216.pdf. Accessed October 1, 2021.

World Bank. (2007). Changing The Face of the waters: The Promise and Challenge of Sustainable Aquaculture. Agriculture And Rural Development. https://documents1.worldbank.org/curated/en/322181468157766884/pdf/416940PAPER0Fa18082137015501PUBLIC1.pdf

WorldFish. (2020). Scoping study in five States/Regions of Myanmar. Small-Scale Aquaculture Investments for Livelihoods and Nutrition in Myanmar (SAIL). WorldFish.

Yigezu, Y. A., Mugera, A., El-Shater, T., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y., & Loss, S. (2018). Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. *Technological Forecasting and Social Change, 134*, 199–206.

Yitayew, A., Abdulai, A., Yigezu, Y. A., Deneke, T. T., & Kassie, G. T. (2021). Impact of agricultural extension services on the adoption of improved wheat variety in Ethiopia: A cluster randomized controlled trial. *World Development, 146*, 105605. https://doi.org/10.1016/j.worlddev.2021.105605

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