Impact of shrimp-fish polyculture practices on small-scale farmers' income in Indonesia

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Abstract. The polyculture practice's ecological benefits are well reported in the literature. However, studies on the impact of the polyculture practice adoption on small-scale farmers' income are scarce. This study employs the propensity score matching method to determine the polyculture practice's impact on small-scale farmers' income using randomly cross-sectional data collected from 350 farmers in Indonesia. The study proved that the adoption has significantly contributed to an increase in farmers income. The study recommends that the polyculture practice could be a model for alleviating poverty and preserving mangrove forests, thus contributing to the achievement of the Sustainable Development Goals, particularly on zero poverty, hunger, decent work and economic growth, climate action and life in the coastal areas of Indonesia.

Key Words: income, SDGs, welfare, propensity score matching, Mahakam delta.

Introduction. The literature related to the polyculture practice's ecological benefits has been well documented. However, studies of the income impact of changing the old practice to the new practice on small-scale farmers in aquaculture are rare. Polyculture, a practice of integrating two or more species, can improve productivity, leading to enhanced small-scale farmers' income and welfare improvement for those who adopt this practice (Bunting 2008). Polyculture is practiced generally in pond or cage aquaculture (Yi & Fitzsimmons 2004), where several aquatic organisms are combined in mutualistic assemblages (Copertino et al 2009; Yuan et al 2010; Jaspe et al 2011).

Even though Indonesia is one of the significant producers in global fish production, with 4.95 million tons (FAO 2018), polyculture in this country faces some challenges, in particular related to the small-scale farmer mindset in adopting a new aquaculture practice. In Mahakam Delta, for instance, some farmers still practice the monoculture in shrimp farming and their reason is that cultivating more than one species creates a potential risk of pathogens entrance into the aquaculture system. Conversely, Zhen-xiong et al (2001) present a detailed analysis in which the polyculture practice has a higher efficiency of nitrogen utilization than the monoculture practice, which improves the water quality. Martinez-Porchas et al (2010) also presented an argumentation in which polyculture could reduce nitrogenous wastes by converting the toxic metabolites into nitrate, which minimizes the environmental impact. Similarly, Belton & Little (2008) argued that shrimp farming contributed to declining ecosystem quality; thus, shrimp farming using polyculture was a strategy to diminish contamination. However, these studies only explore the polyculture practice's ecological benefits without considering its economic benefits.

Purcell et al (2006) explained the advantages of a polyculture practice on increasing economic profitability and efficiency in investment costs. Primavera (1997) also revealed that the cost-benefit ratio would improve when the traditional extensive polyculture ponds were applied to shrimp culture. There is, however, no empirical study of the polyculture practice's impact on small-scale farmer's income when they switched to the polyculture practice from the old practice.

As mentioned above, the polyculture practice potentially provides a profitable business, leading to increased income and poverty alleviation for small-scale farmers. Therefore, this study provides empirical evidence on the impact of the polyculture practice adoption on small-scale farmers' income. Propensity score matching is required to control differences in farmers' demographic, farm characteristics and social capital between those who adopted the polyculture practice and those who did not.

Material and Method

Study area and data collection. The data used in this study originate from a survey of small-scale farmers conducted in the Mahakam Delta. This delta lies in the Kutai Kartanegara Regency, one of the regencies in East Kalimantan Province. In this regency, 67.40% of the recensed 56,990 poor people (leaving with less than approximatively 1 USD per capita, per day) are distributed in rural and coastal areas, including in Mahakam Delta (Central Bureau of Statistics of Kutai Kartanegara 2016; Susilo et al 2017b). This delta covers an area of 5,200 km^2. Fisheries, including shrimp farming is the mainstay of the economy of this area (Susilo et al 2017a).

The present study conducted a survey research by applying a cross-sectional technique. The data were collected from April to June 2019 through a questionnaire and face-to-face interviews. Five villages were selected by purposive sampling based on the many households that practiced the shrimp ponds culture. The five villages were Tani Baru, Muara Pantuan, Sepatin, Salok Palai, and Saliki. 350 farmers were selected that were categorized as shrimp-fish polyculture practices adopters and non-adopters. Unfortunately, there was no complete official census list of farmers in the study area, neither for shrimp-fish polyculture adopters or non-adopters. Therefore, the respondents could not be entirely selected randomly. Alternatively, shrimp-fish polyculture practices adopters were selected according to their willingness to take part in this study. Besides, at least one non-adopter was selected for each adopter from the same village. All obtained respondents were assumed to have some information about the shrimp-fish polyculture practices. After a detailed checking of the completed respondents' answers, 164 shrimp-fish polyculture practices adopters and 186 non-adopters were selected as the analysis base.

Analytical framework

Adoption model. The framework was designed based on the axiom of rationality, implying that a farmer will only select the shrimp-fish polyculture practices if it can generate a profitable balance, under a given set of resource constraints. The discrete choice, nevertheless, to apply the shrimp-fish polyculture practices can be interpreted within the context of random utility. Profit-maximizing producer is assumed to select the shrimp-fish polyculture practices if desirable net utility from adopting (U_i^A) is higher than for non-adopting (U_i^N). A farmer, therefore, will approve a change if the desirable net utility is higher than zero, $U_i^* = U_i^A - U_i^N > 0$. The latent variable model which represents the unobserved net utility that can be indicated as a function of observable elements can be specified as:

$$U_i^* = \sigma Z_i + \varepsilon_i, \quad U_i = 1 \ if \ U_i^* > 0$$

Where:

U_i-a binary indicator variable taking the value of 1 if a farmer adopts the shrimp-fish polyculture practices and 0 if otherwise;

σ-a vector of parameters to be estimated;

Z_i-a vector of explanatory variables;
ε_i-the error term.

Propensity score matching (PSM). Identifying the causal effects of adopting the shrimp-fish polyculture practices on the indicator of outcome (farmers’ income) is difficult due to endogeneity bias: farmers volunteering based on their willingness to participate are non-random respondents which may systematically differ from non-adopters in many socio-economic observable features that may have a direct impact on farmers' income. Therefore, bias estimates will occur when estimating merely on the difference between the mean income of the two groups of farmers. Examining both observable and non-observable attributes is needed to precisely measure impacts by performing random assignments of farmers to the treatments (polyculture system adoption). If the assignments are not random, the selection bias may continue as the observed and unobserved attributes of the farmers may influence the probability of obtaining correct outcome indicators from the treatments.

PSM can be explained as the probability of obtaining a treatment outcome wg\hich is conditional on the pre-treatment attributes (Rosenbaum & Rubin 1983). The treatment is the outcome (farmers' income) and the pretreatment is a set of covariates. A covariate can be an independent variable (such as farmers’ demography, farm characteristics and social capital) or a confounder (unobserved variable). Adding a covariate to a model can improve the accuracy of the results. In PSM, a statistical comparison group is formed, based on a randomly assigned treatment, where individuals receiving a treatment are matched with individuals in the control group, based on observable covariates. Therefore, PSM matches each treated farmer (adopters) with a similar untreated farmer (non-adopters) and estimates the average difference in the outcome (farmers' income) variable between adopters and non-adopters, answering the scientific question: “how would the farmers' income have changed if the adopters had chosen not to adopt”. This permits the description of a causal link between the adoption variable and the outcome variable. Impact estimates based on matched samples are less biased and more reliable than estimates based on the full sample.

This approach assumes that the sample selection bias can be removed by conditioning on observable variables, and proceeds by matching each adopting individuals with one or more non-adopting individuals with comparable observable attributes. Besides, the matching models can identify a causal link between the adoption and the outcome variables by simulating the conditions of an observation in which the treatment group and the control group are randomly assigned. In other words, PSM matches each treated farmer (shrimp-fish polyculture practices adopter) with similar untreated farmers (non-adopters) and determines the average difference in the outcome variables between adopters and non-adopters (Gitonga et al 2013; Ehiakpor et al 2019). Due to a reduced bias, impact estimates based on matched samples are more reliable than estimates based on the full sample (Rubin 2000).

In determining the causal effect of shrimp-fish polyculture practices on farmers' income, consider variables as indicators of farmers who have adopted the shrimp-fish polyculture practices (treatment group) taking the value of 1 if treated and 0 if otherwise. In the PSM method, shrimp-fish polyculture practices adoption is displayed as a selected dependent variable applying a logit or probit model. Afterward, the propensity score for each observation is estimated. The shrimp-fish polyculture practices adoption can be specified as:

$$p(X) = \Pr[P = 1 \mid X] = \mathrm{E}[P \mid X]; \quad p(X) = F\{h(X_i)\}$$

Where:
$p(X)$-propensity score;
$\Pr$-the probability of shrimp-fish polyculture practices adoption (0,1) conditional on X, a vector of observed covariates;

$F\{.\}$-a logit or probit model with logistic or normal cumulative distribution function, respectively.

In this study, a probit model is employed as the first stage to estimate the propensity scores of adoption in the shrimp-fish polyculture practices.

After propensity score estimation, each treated individual in the sample is matched with one or many control individuals (non-adopters) with similar propensity score applying the two matching methods, nearest neighbor matching (NNM), and kernel-based matching (KBM). It is also critical to run a balancing test to discover whether individuals within the two groups have similar propensity scores. Besides, the balancing property serves to ascertain whether the differences in the covariates between the treated and control groups have been removed, in which case the matched comparison group can be recognized as a reasonable counterfactual (Caliendo & Kopeinig 2008). This study applies the mean absolute standardized bias (MASB) method, the most widely employed in literature, in which the standardized difference should be less than 20% to be verified as acceptable in the matching process (Rosenbaum & Rubin 1985).

Furthermore, the average treatment effect on the treated (ATT) is determined as the weighted difference between treated (adopter) and matched controls (Gebrehiwot 2015). ATT estimates the impact of shrimp-fish polyculture practices on farmers who have adopted the practice, as specified:

$$ATT = E[\Delta_i \mid P_i = 1] = E\left[\xi_{1i} \mid P_i = 1\right] - E\left[\xi_{0i} \mid P_i = 0\right]$$

Where:

$E[\Delta_i \mid P_i = 1]$-the expected treatment effect;

P_i-participation in shrimp-fish polyculture practices adoption taking two values: $P_i = 1$ if a farmer is an adopter and $P_i = 0$ if a farmer is non-adopter;

ξ_{1i}-the outcome indicator of adopter i;

ξ_{0i}-the outcome indicator of non-adopter i.

The ATT points to the average difference found in the case in which farmers in the polyculture system adoption group would have accepted the treatment compared with the case in which none of these farmers in the polyculture system adoption group would have accepted the treatment (Danso-abbeam & Baiyegunhi 2018).

The PSM estimation may not be robust if unobserved covariates concurrently affect the shrimp-fish polyculture practices adoption and outcome variables. Therefore, this study also assesses the robustness of matching estimations to a potential presence of unobserved covariates (Rosenbaum 2002).

Results and Discussion

Descriptive statistics. Table 1 presents the summary statistics of the dependent, outcome, and independent variables. The adoption of shrimp-fish polyculture practices is a dependent variable applied for the probit estimation and used as a treatment binary variable, with the possible values of: one (1) if the farmer adopts the practice and zero (0) otherwise.

As shown in Table 1, only 47% of farmers have been practicing shrimp-fish polyculture practices, indicating a considerable proportion of farmers in the study area have not yet adopted this practice.

Farmers' income is considered as an outcome variable. Farmers' income comprises revenues of farm production minus operational expenses covering one year. As it could be seen from Table 1, the mean income of the farmers was USD 394.17 ha^{-1} annually. There was a statistical difference in outcome variables between adopters and non-adopters of the shrimp-fish polyculture practices.

Table 1

Summary of descriptive statistics of sample small-scale farmers

Variable	*Pooled sample (N=350)*		*Adopters (N=164)*		*Non-adopters (N=186)*		*Diff.*
	Mean	*Std. dev*	*Mean*	*Std. dev*	*Mean*	*Std. dev*	
Dependent and outcome variables							
Shrimp-fish polyculture practices adoption (1=yes, 0=no)	0.47	0.50	1		0		
Income (USD ha^{-1} $year^{-1}$)	403.29	147.16	441.49	121.69	351.64	154.95	89.86***
Independent variables							
Farmers' demographics							
Age of farmer (years)	41.47	9.45	41.62	10.53	40.77	8.40	0.85
Household size (numbers)	3.33	1.13	3.39	1.12	3.27	1.13	0.12
Education level (years)	7.09	2.02	7.49	2.38	6.74	1.57	0.75***
Experience (years)	12.16	6.69	11.84	6.34	12.45	6.99	-0.61
Farm characteristics							
Pond size (ha)	12.02	12.08	12.74	22.21	11.38	10.72	1.36
Pond age (years)	19.21	7.54	18.64	7.23	19.71	7.78	-1.07
Pond ownership status (1=owner, 0=otherwise)	0.71	0.45	0.77	0.42	0.66	0.47	0.11**
Received credit (1=yes, 0=no)	0.25	0.43	0.23	0.42	0.26	0.44	-0.03
Social capital							
Member of farmer association (1=yes, 0=no)	0.14	0.34	0.19	0.40	0.09	0.28	0.10***
Training (1=yes, 0=no)	0.56	0.50	0.62	0.49	0.50	0.50	0.12**
Visits of extension agent (numbers $year^{-1}$)	2.23	2.78	2.66	3.06	1.85	2.45	0.81***

***, and ** indicate significance level at 1%, and 5%, respectively.

Independent variables consist of farmers' demographic, farm characteristics, and social-capital. The mean age of the farmers in the study area was 42 years, which was within the active and productive life phase. However, there was a statistically insignificant difference between the 2 groups. The majority of farmers' experience was 12 years, with an average household size of 3. Both experienced and household size did not record a statistical difference between the groups. On average, the education level of farmers was 7 years or primary school, with significant differences between adopters and non-adopters. It indicates that adopters were statistically more educated than non-adopters.

In terms of farm characteristics, the mean pond size and the pond age for the full sample were about 12 ha and 19 years, respectively, with no significant difference between the two groups. Similarly, about 25% of farmers have received fisheries credit facilities, with insignificant differences between the adopters and non-adopters. The table further shows that the proportion of pond owner respondents in the full sample was significantly more dominant (71%), with a statistical difference (5% level of significance) between the two groups. Furthermore, all variables in social-capital factors were significantly different between adopters and non-adopters, indicating that the social-capital was a crucial factor in disseminating information and knowledge in particular related to the mono-cultures to poly-culture change management in small-scale farmers. This study also examined how the number of extension visits influences people's willingness to adopt the polyculture system, where “extension” refers to the process of transferring knowledge and skills to farmers, by an agent.

Determinants of shrimp-fish polyculture practices adoption. Table 2 presents the probit model estimating the affecting factors of the adoption of shrimp-fish polyculture practices. This model is also the first step to empirically estimate the propensity scores for the impact in the PSM model. The probit model provides a good fit for the data, since the value of The Likelihood Ratio-Chi-Square test (39.98) was statistically significant at 1% level of significance, indicating that the selected covariates presented a reasonable estimation of the conditional density of adoption.

Table 2

Determinants of shrimp-fish polyculture practices adoption

Variables	*Coefficient*	*Std. error*	*Marginal effect*
	Farmers' demographics		
Age of farmer	0.002	0.998	0.001
Household size	0.030	0,069	0.012
Education level	0.096**	0.039	0.038**
Experience	-0.018	0.012	-0.007
	Farm characteristics		
Pond size	0.008	0.005	0.003
Pond age	-0.017*	0.01	-0.007*
Pond ownership status	0.351**	0.168	0.140**
Received credit	0.02	0.171	0.008
	Social capital		
Member of farmer association	0.501**	0.212	0.199**
Training	0.352**	0.156	0.140**
Visits of extension agent	0.056**	0.026	0.022**
Constant	-1.15**	0.476	
	Model diagnosis		
Log–likelihood	-221.91		
LR Chi Square	39.98***		
Pseudo R^2	0.08		
Observations	350		

***, **, and * indicate significance level at 1%, 5%, and 10%, respectively.

As expected, and corresponding to the literature (Ofuoku et al 2008; Wandji et al 2012; Salazar et al 2018; Susilo et al 2019), education level had a significantly positive impact associated with increased probability of shrimp-fish polyculture practices adoption. An additional level of education was associated with a 3.83% increase in the chances of adopting shrimp-fish polyculture practices. These results explain that the farmers who have higher level of education understand and construe information rightly, resulting in profiting more from adoption.

The farm characteristics that determine the adoption of shrimp-fish polyculture practices are pond age and pond ownership status. Farmers with older age ponds had a 0.70% lower chance of adopting shrimp-fish polyculture practices. A possible explanation for these findings is that most farmers in the study area are knowledgeable in pond lifecycles like quadratic curve, such as it produces more outputs as it ages, takes to its peak, and then decreases. Therefore, farmers have no motivation to increase the outputs of their aged and less productive ponds. These results are in line with the results of Noryadi et al (2006), Bosma et al (2012), Susilo et al (2018) that after 5 years, an average of shrimp production in the study area was only 45 kg ha yearly, declining from the first year period that produced shrimps approximately yearly 100-300 kg ha^{-1}. Also, Avnimelech & Ritvo (2003) revealed that after 3-5 years, shrimp production declined due to gradual acidification of mangrove soils. Furthermore, pond ownership status had a significantly positive relationship with the adoption of shrimp-fish polyculture practices, implying that farmers as owners were more likely to adopt. These findings are also in line with Fosu-Mensah et al (2012) who recorded that land ownership was significant for newer adoptions. The marginal effect showed that when a farmer owns the pond, the probability to adopt the shrimp-fish polyculture practices increased by 14%.

The positive and statistically significant estimated coefficient of social-capital factors such as being a member of farmer association, attending training and visits from extension agents highlights the essence of communication, technical knowledge and information dissemination in newer practices adoption among farmers. The estimated coefficient for a member of farmer association was significant and positively associated with the likelihood of adopting the shrimp-fish polyculture practices, at a statistical significance of 5%. The marginal effect of a unit increase in farmers' membership in farmer association increased the probability of adopting the shrimp-fish polyculture practices to 0.199 (19.90%) more chance in adoption if farmers' were a member of farmer association. These results suggest that farmer association is the center of information and knowledge exchange for farmers to obtain new information about newer practices adoption. Also, farmers can discuss in group meetings and learn from each other to improve their skills to reach their goals. Rogers (1995) and Kumar et al (2018) confirm that the critical factors of successful technology adoption were peer communication on professional and organizational skills.

The training variable has a positive correlation with the adoption. The results suggest that a farmer who has attended aquaculture training was 12% more likely to adopt shrimp-fish polyculture practices. The findings are consistent with Brown & Fadillah (2013), who determine that the probability of local farmers to adopt polyculture practices in Indonesia is enhanced by the technical and hands-on training. Previous studies also revealed the same benefits from aquaculture training for farmers (Radheyshyam et al 2013). The variable "extension" was positively related to the increasing probability of adoption with a statistical significance of 5%. The marginal effect expressed that the farmers' likelihood of adopting the shrimp-fish polyculture practices rises by 22% when visits from extension agents increase in providing aquaculture information and knowledge in the study area. Many studies have revealed that contacts with extension personnel in the aquaculture field was crucial in determining the new adoption of a technology or farming system (Murshed-E-Jahan et al 2008; Wandji et al 2012).

Income impacts of shrimp-fish polyculture practices adoption. The effects of shrimp-fish polyculture practices adoption were measured using farmer's income as outcome variable. Figure 1 presents the histogram of the distributions of the estimated propensity scores for the adopters and non-adopters of the shrimp-fish polyculture practices for visual inspection. The results from Figure 1 indicated that both the treated (adopters) and untreated (non-adopters) groups had perfectly overlapped their propensity score distributions. Therefore, the common support condition of the propensity score matching has been satisfied, and the two groups had similar characteristics. The upper of the histogram referred to the propensity score distribution for the treated (adopters), and the bottom recorded to the untreated (non-adopters). Moreover, the density distribution was shown by the vertical axis.

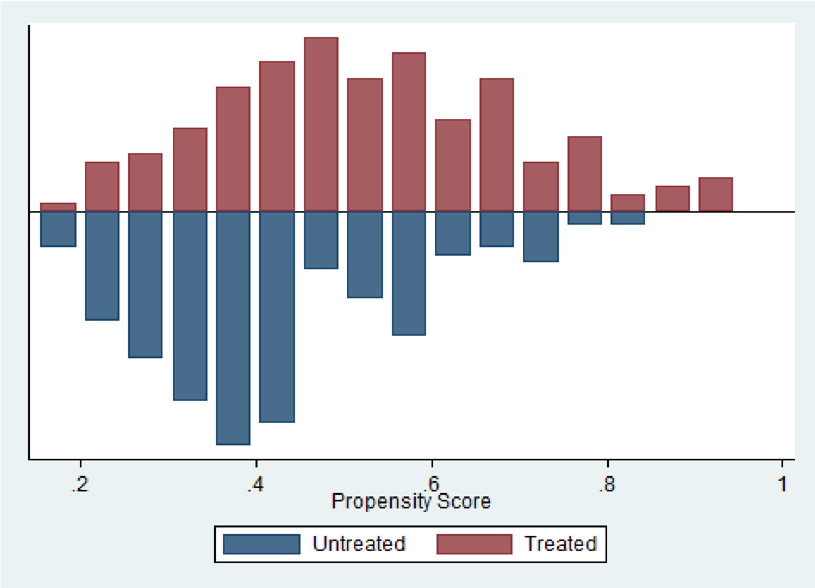

Figure 1. Propensity score distribution and common support.

The study implemented a balancing test on the covariates to evaluate if there were statistical differences between adopters and non-adopters of shrimp-fish polyculture practices. When the two groups were not statistically significant, accurate matching was attained (Caliendo & Kopeinig 2008). The results in Table 3 show that the two groups had broadly similar attributes and differed statistically between their mean covariates after matching. In contrast, the unmatched sample showed statistically significant differences in some covariates between the treated (adopters) and untreated (non-adopters) groups.

Table 3

Test of matching quality

Variable	*Unmatched sample*			*Matched sample*			*% Bias reduction*
	Treated	*Control*	*Diff. p-value*	*Treated*	*Control*	*Diff. p-value*	
Age of farmer	41.62	40.77	0.40	41.56	41.66	0.93	87.8
Household size	3.39	3.27	0.34	3.38	3.41	0.81	72.8
Education level	7.49	6.74	0.00***	7.36	7.24	0.60	84.4
Experience	11.84	12.45	0.39	11.93	11.77	0.83	72.8
Pond size	12.74	11.39	0.46	11.65	10.93	0.65	46.8
Pond age	18.64	19.71	0.19	18.69	18.57	0.88	88.2
Pond ownership status	0.77	0.66	0.03**	0,76	0.75	0.84	91.1
Received credit	0.23	0.26	0.49	0.23	0.25	0.67	34.5
Member of farmer association	0.19	0.09	0.00***	0.18	0.19	0.84	92.2
Training	0.62	0.5	0.02**	0.61	0.62	0.80	88.5
Visits of extension agent	2.66	1.85	0.00***	2.62	2.69	0.83	91.3

***, and ** indicate significance level at 1%, and 5%, respectively.

The indicators of matching algorithms before and after matching were examined to ensure the matching technique quality, as suggested by Rosenbaum & Rubin (1983). Table 4 shows that the Pseudo R2 was considerably reduced, from 8.3% before to 0.3 - 1.3% after matching. The value of the likelihood Ratio-Chi-Square test was statistically rejected after matching, in contrast to before matching. The standardized mean difference in the covariates, applied in the propensity score, was lessened from 18.6% before matching to a range of 3.0-7.0% after matching, providing a total bias reduction in the range of 61.65–82.63%. Due to the low Pseudo R2, to the insignificant p-value of the likelihood Ratio-Chi-Square test and to the low mean standardized bias and to the significant reduction of the total bias after matching, the specification of the propensity score estimation process was considered successful, in terms of balancing the distribution of covariates between the two groups, and could be employed to estimate the impact of shrimp-fish polyculture practices adoption.

Table 4

Indicators of quality before and after matching

Matching algorithm	*Pseudo R^2*		*LR X^2 (p-value)*		*Mean standardized bias*		*Total % bias reduction*
	Before	*After*	*Before*	*After*	*Before*	*After*	
NNM[a]	0.083	0.013	39.98***	5.76	18.60	7.00	61.65
NNM[b]	0.083	0.008	39.98***	3.57	18.60	5.10	70.19
KBM[c]	0.083	0.003	39.98***	1.38	18.60	3.20	81.04
KBM[d]	0.083	0.003	39.98***	1.00	18.60	3.00	82.63

***significance level at 1%; NNM[a]-single nearest neighbor matching with replacement and common support; NNM [b]-5 nearest neighbor matching with replacement and common support; KBM[c]-kernel-based matching with band width 0.06 and common support; KBM[d]-kernel-based matching with band width 0.03 and common support.

Table 5 shows the impact of shrimp-fish polyculture practices on farmer's income. Four primary matching algorithms are applied consisting of (1) single nearest neighbor matching with replacement and common support, (2) five nearest neighbor matching with replacement and common support, (3) kernel-based matching with bandwidth 0.06 and common support and (4) kernel-based matching with 0.03 bandwidth and common support. The study employs farmer's income as leading indicator. Overall, the adoption of shrimp-fish polyculture practices has a positive and robust effect on farmer's income in terms. The results indicated that farmer's income per hectare annually increased by nearly USD 65.81 as a result of the adoption. It explains that farmers made the correct decision to adopt shrimp-fish polyculture practices. For non-adopters, annual farmer income would increase by nearly USD 65.13 ha^{-1} if they were to adopt the shrimp-fish polyculture practices. These findings are in line with (Aghuzbeni et al 2017), who explain that polyculture practices are economically more efficient, having a better stability related to environmental conditions and a higher productivity compared to monoculture practices, concluding on the improving of farmers' income as an adoption impact.

Table 5

Impact of shrimp-fish polyculture practices on Farmer's income

Outcome variable	*Matching algorithm*	*ATT*			*ATU*		
		Adopters	*Non-adopters*	*Diff.*	*Adopters*	*Non-adopters*	*Diff.*
Farmers' income	NNM[a]	6.24	5.31	0.93***	5.89	4.97	0.92***
	NNM[b]	6.24	5.43	0.81***	5.82	4.97	0.85***
	KBM[c]	6.23	5.25	0.98***	5.86	4.97	0.89***
	KBM[d]	6.23	5.32	0.91***	5.82	4.97	0.85***

*** significance level at 1%; ATT-average treatment effect on the treated; ATU-average treatment effect on the untreated; [a] NNM-single nearest neighbor matching with replacement and common support; [b] NNM-five nearest neighbor matching with replacement and common support; [c] KBM-kernel-based matching with band width 0.06 and common support; [d] KBM-kernel-based matching with band width 0.03 and common support.

Sensitivity analysis. The critical assumption of the PSM model is that farmers' decision to adopt in shrimp-fish polyculture practices is utterly dependent on observed factors, not on unobserved factors. Therefore, the sensitivity analysis with Rosenbaum bounds was applied to evaluate the robustness of matching estimations to a potential presence of unobserved covariates (Rosenbaum 2002). Table 6 presents the results of Rosenbaum bound sensitivity for farmers' income using a single nearest neighbor matching with replacement and common support.

Table 6

Rosenbaum bounds sensitivity analysis

*Gamma (Γ)**	*Wilconxon statistics*	
	Upper bound sig. level	*Lower bound sig. level*
1	0.00	0.00
1.1	0.00	0.00
1.2	0.00	0.00
1.3	0.00	0.00
1.4	0.01	0.00
1.5	0.02	0.00
1.6	0.04	0.00
1.7	0.08	0.00
1.8	0.14	0.00
1.9	0.21	0.00
2	0.29	0.00

*log odds of differential assignment due to unobserved factors.

The results reveal that farmers' income was insensitive to the presence of hidden bias or unobservable confounders. For instance, the causal effects of the shrimp-fish polyculture practices on farmers' income in the study area would only change at the statistic bound (Γ)=1.8 (i.e. the upper critical gamma cut-off value). When the sensitivity test was equal to 1.8, the upper bound of the p-value became insignificant. It implies that the likelihood of accepting treatment by two farmers of similar characteristics can differ by up 80% without changing the interpretation of the treatment effects.

Conclusions. This study has investigated the potential impact of shrimp-fish polyculture practices adoption on farmers' income in Mahakam Delta, Indonesia, by using the PSM technique. The probit estimate of the PSM was applied to recognize the determinants of adoption. The findings show that the probability of adoption was influenced by farmers' demographic, farm characteristics, and social-capital factors. These results can be implemented to target small-scale farm level programs oriented towards the adoption of shrimp-fish polyculture practices to develop knowledge and skills in improving their income. For instance, since the education level has a positive and significant impact on the adoption, implementing context-based informal education programs can be crucial for complementing the necessary information and knowledge and for stimulating income from the pond productivity increase through adoption. Another finding, pond age is a determinant farm characteristic, providing a negative response to the adoption. The recovery and management of old age pond practices by stakeholders, including incentives, are required for supporting small-scale farmers by stimulating productivity and ultimately for encouraging them to adopt the shrimp-fish polyculture practices. Another important finding from the study's result is the significant role of the social-capital factors such as farmer association membership, training and visits from the extension agents. Policy interventions are required for developing the farmers' association membership and for increasing the training attendance, but also for strengthening the extension institutions able to promote and accelerate shrimp-fish polyculture practices.

The empirical findings reveal that the increase of farmers' income is highly influenced by the adoption of shrimp-fish polyculture practices, suggesting that decisionmakers can promote the advantages of shrimp-fish polyculture practices in the study area. Moreover, shrimp-fish polyculture practices can commit to Indonesia's economic growth, being a model in poverty alleviation in coastal areas of Indonesia, which ultimately contributes to the achievement of the Sustainable Development Goals (SDGs), particularly on zero poverty (SDG 1), hunger (SDG 2) and decent work and economic growth (SDG 8). Regarding the damages to mangrove forests in the study area by farmers due to the expansion of shrimp pond areas to improve their income, this adoption could be an alternative practice in preserving mangrove forests, in order to achieve the SDGs for goal 13 (climate action) and 15 (life on land). Finally, the current work recommends further studies, such as additional empirical investigations to evaluate the biophysical feasibility of shrimp ponds, based on both old and newer practices, and to determine what factors are influencing shrimp or fish productivity.

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