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Abstract. The benefits of polyculture system adoption in the shrimp farming have been well documented and adoption significant progress has been made to bring it to reality. In the developing countries, the farmers' response regarding the adoption of the polyculture system is still weak, therefore the current study analyzed the barriers in the Indonesian case, by focusing on the main factors affecting farmers' adoption decision. A comprehensive survey of 250 farmers was carried out, including 118 farmers as adopters and 132 farmers as non-adopters. Data were examined by employing a logistic regression model. The results revealed that among the demographic factors, the family size and education level of the farmer are crucial variables demonstrating the likelihood of adoption. In addition, among the economic factors, the expected benefits and cost of adoption variables significantly influence the likelihood of adoption. Membership of a farmers' group and aquaculture training, among the social capital factors, were also significant and positively correlated to the likelihood of farmer in adopting. The findings were valuable for decision-makers in recognizing what determined farmers' decision-making behavior and identifying those farmers who would most likely apply the polyculture system in the future.
Key Words: adoption, shrimp farming, logistic regression.

Introduction. Worldwide, aquaculture is an important food production sector which has been continuously growing at a fast pace over the past years. According to the Food and Agriculture Organization (2018), aquaculture in 2016 provided more than 30% of the national whole fish production in different 22 countries. Moreover, the traded value of the global aquaculture production was assessed at USD 243.5 billion, with production estimated at approximately 110.2 million tons. For fish species, over 90% of aquaculture production originated in Asia. Aquaculture of Indonesia is the primary source of employment and income for the coastal community. The absolute value of Indonesia aquaculture food fish production in 2016 was calculated at 4.95 million tons, accounting for 6.20% of the global fish production (FAO 2018). The shrimp sub-sector dominates aquaculture in Indonesia with a production estimated at approximately 58.14 million tons. Shrimp production in 2017 accounted for 31.06 percent of the whole Indonesian aquaculture (MMAF Indonesia 2018). The dominant shrimp farmed species in Indonesia are Penaeid shrimp (*Litopenaeus vannamei* and *Penaeus monodon*). Indonesia is also one of the significant shrimp producers in the world, contributing to 8.8 percent of the global shrimp production (FAO 2015; Portley 2016).

Mahakam Delta is one of the areas in Indonesia with potential for aquaculture development. The regional livelihood is about 5,542 households or 18.32% of the total livelihood in Mahakam Delta, which is entirely dependent on aquaculture (Central Bureau of Statistics of Kutai Kartanegara 2016). Most of people cultivate giant tiger prawn (*Penaeus monodon*), a native species, as single primary species. However, they can also harvest other shrimps such as the Indian white prawn (*P. indicus*) and speckled shrimp (*Metapenaeus monoceros*) originating from wild juveniles entered during the tidal exchange (Bunting 2013; Susilo et al 2018). Small-scale farms characterize shrimp farming in Mahakam Delta. By the monoculture system, shrimp farming in the Mahakam Delta brought many benefits to the local communities, particularly in the late 1990s. Shrimp farming captured the attention of the local communities and migrants, due to relatively high shrimp prices in local currency resulting from a high export demand for shrimp, supported by the Asian monetary crisis (Sidik 2009; Powell & Osbeck 2010; Bosma et al 2012b). Therefore, shrimp farming is an important source of income for local communities and has the potential of contributing to poverty alleviation in Mahakam Delta.

In recent years, the productivity of shrimp farming in the Mahakam Delta has been reduced drastically due to the poor water quality, environmental deterioration, and outbreaks of shrimp diseases. Moreover, shrimp farming in Indonesia had an experience of declining productivity in the 1990s, due to White Spot Syndrome Virus (WSSV), in particular following the intensification and densification of Penaeus Monodon farming (Kusumastanto et al 1998). Farmers who implement a monoculture system are vulnerable when facing the WSSV attack. This infection was a serious problem causing mass mortality of shrimp and affecting the farmers' revenues: those who only cultivate shrimp as a single primary species cannot obtain an alternative income. The WSSV attack, resulting in a decline in shrimp productivity, also occurred in other countries such as Thailand (Flegel 1997), Honduras (Valderrama & Engle 2004), Iran (Salehi 2010), Bangladesh (Karim et al 2011), and India (Kalaimani et al 2013).

Some strategies have been implemented by the government to reduce these problems and to preserve the sustainability of local communities' shrimp production. One of those strategies is a polyculture. Polyculture is one of the aquaculture systems referring to multi-trophic aquaculture, co-culture, or aquaculture that integrates two or more species (Bunting 2008). In shrimp farming, polyculture has many benefits for farmers. For instance, this system can lessen the environmental impact of nitrogenous wastes (Martinez-Porchas et al 2010), reduces contamination (Belton & Little 2008), and enhances disease resistance to pathogens (Martinez-Porchas et al 2010). It can also increase the production from primary and secondary stocks and can manage optimum water quality in specific aquaculture systems (Muangkeow et al 2007; Troell et al 2009). Moreover, several studies have demonstrated the combination of culturing shrimp with other species, such as milkfish (Jaspe et al 2011), seaweed (Lombardi et al 2006), tilapia (Yuan et al 2010) and several species of macroalgae and giant oyster (Martinez-Cordova & Martínez-Porchas 2006; Da Silva-Copertino et al 2009).

Some farmers in the Mahakam Delta apply polyculture by adding milkfish seeds to their shrimp ponds. They assume that *P. monodon* has low survival rates, being susceptible to WSSV attacks. Comparatively milkfish (*Chanos chanos*) is easy to culture. Thus, through the previous system, farmers can reduce the risks of shrimp harvest failure or loss of income. Unfortunately, even though the adoption of polyculture has been promoted through the Ministry of Marine Affairs and Fisheries (MMAF) and by the experts, the polyculture has not been widely welcomed by farmers in the Mahakam Delta. Most of the farmers still practice monoculture as the shrimp farming management method.

Therefore, it is crucial to improve awareness among the small-scale farmers regarding the benefits of polyculture adoption. An understanding of the factors stimulating a small-scale farmer's decision to adopt the polyculture system is important in order to provide insights and investigate target variables that optimize the adoption of an appropriate system. Studies related to factors influencing on new practices and technology adoption in agriculture have been well documented (Mariano et al 2012; Bosma et al 2012a; Gebrezgabher et al 2015; Nigussie et al 2017). However, studies that focus on factors affecting the decisions' small-scale farmers to adopt the polyculture system in shrimp farming are limited. Furthermore, in the adoption of rice-fish farming, several studies revealed that demographic characteristics and institutional affected the farmers' decision to adopt the new system (Noorhosseini & Allahyari 2012; Bosma et al

2012a). Followed those findings, this study hypothesizes that the small-scale farmer's decision making on adopting the polyculture is strongly determined by demographic, economic, and social capital factors. Therefore, the primary objective of this study is to investigate factors influencing small-scale farmers' decision to adopt the polyculture system. The findings obtained from this study may provide support for policymakers, facilitating the choice of a proper orientation, and target an extension of the aquaculture development in the long-term in order to reach the sustainable livelihood goals.

Material and Method. The sampling method was devised to collect data required to review factors affecting small-scale farmers' determination to adopt the shrimp pond polyculture system in the Mahakam Delta. The data were presented in logistic regression model to examine the hypothesis mentioned above.

Description of the study sites. The study was carried out in five villages in the Mahakam Delta, Indonesia: Sepatin, Muara Pantuan, Tani Baru, Salok Palai, and Saliki (Figure 1). The villages were purposively selected based on the highest number of farmers, the distribution of the vital shrimp farming area, and the similarity concerning characteristics of the shrimp pond and shrimp species. The survey was undertaken from April to June 2019 with face-to-face interviews. The questionnaire was pre-tested by examining twenty farmers to confirm that the respondents had adequate knowledge to respond to all the points in the questionnaire. The interview duration was of about an hour, focused on shrimp farming system, demographic characteristic, economic and social capital features. Three hundred questionnaires were distributed, 250 were completed including 118 farmers that had adopted the polyculture system and 132 respondents who did not perform the polyculture system.

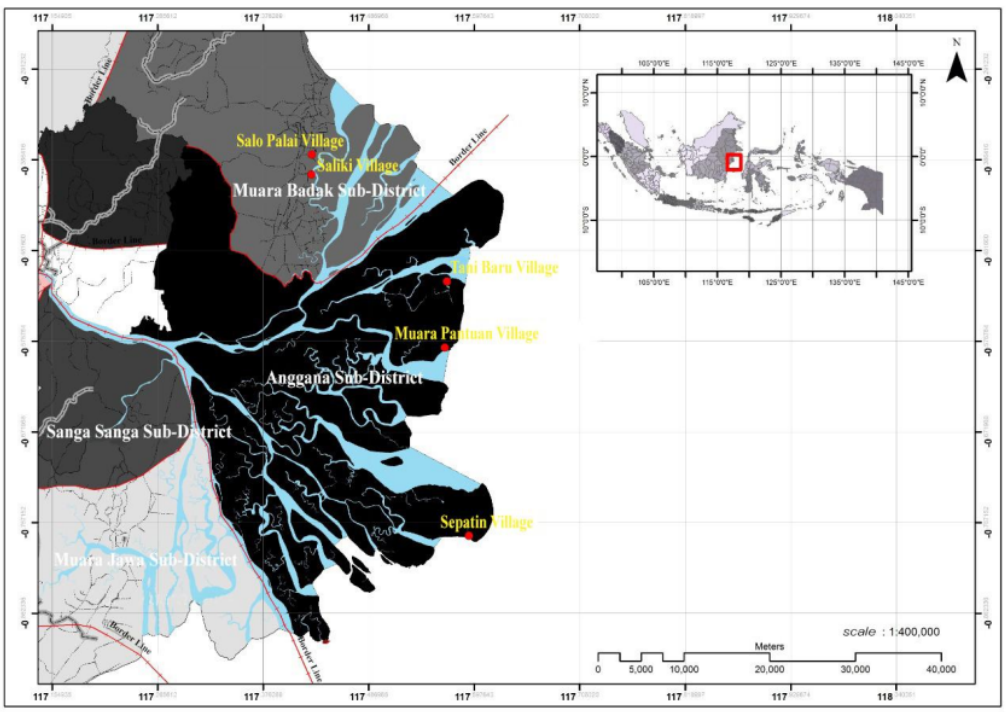

Figure 1. Study sites.

Statistical analysis. The attributes for the two groups were analyzed by employing a logistic regression model.

The dependent variable was the adoption of the polyculture system and it was dichotomized with a value of 1 if a farmer was an adopter of a polyculture system and 0 if a non-adopter. In this model, the probability of an individual farmer adopting polyculture expressed as *Prob* $(Y=1|x)$, given demographics, economic and social capital factors x', and β is the impact of the change in x' on the probability. $\Lambda(x'\beta)$ is the value of the logistic cumulative density function linked with each possible value of the underlying index. The model was specified as follows:

$$Prob(Y=1|x) = \Lambda(\boldsymbol{x}'\beta) = \frac{e^{x'\beta}}{\left(1+e^{x'\beta}\right)^2}\beta_j = \frac{\exp(\boldsymbol{x}'\beta)}{1+\exp(\boldsymbol{x}'\beta)}$$

With marginal effect for normal distribution:

$$\frac{\partial p}{\partial x_j} = \Lambda(\boldsymbol{x}'\beta)[1-\Lambda(\boldsymbol{x}'\beta)]\beta_j = \frac{e^{x'\beta}}{(1+e^{x'\beta})^2}\beta_j$$

The marginal effects describe the probability of farmers adopting polyculture system. Marginal effects are the change in predicted probability related to changes in explanatory variables of the logit model. In other words, marginal effects are defined as the effect of a unit change in a regressor on the probability that a farmer will adopt polyculture.

The coefficients in the logistic regression model were measured by applying a maximum likelihood estimation and served to designate the direction of influence on the probability. The marginal effect of each independent variable was identified and indicated by the estimated changes in probability. Table 1 presents the definition and measurement of variables employed for analysis. Age, family size, education level, experience, and extension were listed as continuous variables. The other variables, namely expected benefits of adoption, cost of adoption, group, and training, were entered in the model as dummy variables.

Table 1

Definition and measurement of variables included in the logistic regression model

Variables	*Type*	*Definition and measurement*
Dependent variable		
Polyculture adoption	Dummy	Adopter, 1; Non-adopter, 0
Independent variable		
Demographic factors		
Age	Continuous	Age of farmer in years
Family size	Continuous	Number of family members
Education level	Continuous	Formal education of farmer in years
Experience	Continuous	Number of years in experience
Economic factors		
Expected benefits of adoption	Dummy	High expected benefits, 1; otherwise, 0
Cost of adoption	Dummy	Affordable, 1; otherwise, 0
Social capital factors		
Farmers' group	Dummy	Member of a farmers' group, 1; otherwise, 0
Aquaculture training	Dummy	The farmer has attended the aquaculture training, 1; otherwise, 0
Extension	Continuous	Number of visits of extension agent each year

Results and discussion

Descriptive statistics. Table 2 displays a descriptive analysis of the independent variables employed in the estimation process. Of the 250 samples, 118 farmers (47.20%) are adopters, while 132 farmers (52.80%) are non–adopters. The average age of farmers was situated in the productive life phase, fact suggested by the mean actual of 40.26 years old, with insignificant differences between the two groups. Family size variable had mean differences between the groups. Family size having three members was significantly more dominant for adopters than for non-adopters. It indicates that a farmer has at least three children who can be potential drivers of the polyculture system adoption. Mostly, the education level of farmers was primary school, fact indicated by the mean actual of 7.22 years, with significant differences between adopters and non-adopters. It implies that the polyculture system adopters were significantly more educated than non-adopters. On average, the actual mean farming experience was 12.73 years, with statistically insignificant differences between the groups. In terms of economic factors, expected benefits and adoption cost variables had mean differences between adopters and non-adopters. Adopters were more likely to consider the obtained benefits and cost incurred if they engaged in the polyculture system adoption than non-adopters. Similarly, Table 2 presents that social capital factors were also significantly different between the polyculture system adopters and non-adopters. For instance, rates of farmers' group membership and attended aquaculture training differed significantly between adopters and non–adopters, indicating that adopters were more active than non-adopters in obtaining knowledge regularly, through social interactions within farmers' organizations and aquaculture practices.

Table 2

Descriptive statistic of respondents

Variables	*All*		*Adopter*		*Non-adopter*		*Diff*	
	Mean	*Std. dev.*	*Mean*	*Std. dev.*	*Mean*	*Std. dev.*		
Demographic factors								
Age	40.26	10.25	40.42	10.95	40.12	9.62	0.30	
Family size	2.79	1.29	3.10	1.19	2.52	1.32	0.58	***
Education	7.22	2.10	7.95	2.42	6.57	1.49	1.38	***
Experience	12.73	6.80	12.73	5.91	12.72	7.52	0.01	
Economic factors								
Expected benefits of adoption	0.50	0.50	0.80	0.40	0.24	0.43	0.56	***
Cost of adoption	0.34	0.48	0.03	0.16	0.63	0.48	-0.60	***
Social capital factors								
Farmers' group	0.12	0.30	0.20	0.40	0.05	0.21	0.15	***
Aquaculture training	0.54	0.50	0.67	0.47	0.42	0.50	0.25	***
Extension	0.48	0.95	0.52	1.07	0.45	0.83	0.07	

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

Parameter estimates of polyculture system adoption. Table 3 displays the results of the estimated parameters of the independent variables that were hypothesized to affect farmers' decision to adopt the polyculture system. Since the coefficient result only reveals the direction of change and not the magnitude of change or the probability of polyculture system adoption, the marginal effects are also investigated and included in the table.

The estimated logistic regression model was appropriate for the data, since the value of The Likelihood Ratio-Chi-Square test (37.44) was significant at 1% level of significance, implying that the independent variables were qualified to explain the variations in the dependent variable. Also, the estimation indicating Pseudo R^2 (0.47) was judged to be indicative of the good fit to the model rules due to a value ranging from 0.2 to 0.4 (McFadden 1979). Moreover, the predicted probability of adoption was 0.8610, indicating a probability of about 86.10% for the willingness to adopt the polyculture system by the farmers in the Mahakam Delta. Based on the validation data integrity, this study concluded that the applied logistic regression model had a good fitness.

Among the demographic factors shown in Table 3, family size had a significantly positive relationship with the polyculture system adoption ($p<0.01$), indicating that farmers with larger family size were more likely to adopt polyculture system. This finding is in line with the results by Noorhosseini & Allahyari (2012) and Susilo et al (2018) that family size is an essential parameter for the adoption of the new system. Moreover, the marginal effect, when the family size of the farmer increases by one member, influences the farmers' probability of adopting the polyculture system by an increase of 15%, ceteris paribus. These findings contradict the study conducted by Kapanda et al (2005), which has not considered the family size to be important in the adoption. Similarly, other previous studies revealed that the family size is insignificant for newer adoptions (Ofuoku et al 2008; Islam et al 2015; Sereenonchai & Arunrat 2019).

The model exhibited a significant positive relationship ($p<0.05$) between the education level of farmers and the probability of the polyculture system adoption. It demonstrated that well-educated farmers were more likely to adopt the polyculture system. It implied that the education level enabled the farmers to accept the information and understand it readily and lead them to adopt a newer system for increasing their income, easier and faster than lower educated farmers. This finding is in line with Ofuoku et al (2008) who recorded that fish production technologies improve e with the increase of the education level. Also, the estimated marginal effect of education level variable implied that the farmers' probability of adopting the polyculture system increases by 5% when there are single unit improvements in education level, ceteris paribus.

Additionally, the economic factors, expected benefits and cost of adoption included, were found to be significantly associated with the adoption rate. The polyculture system adoption's expected benefits variable was statistically significant at 5% and had a positive coefficient. It indicates that if farmers require benefits from adopting the polyculture system to be higher than their current system of shrimp farming, they are most likely to select it and vice versa. The marginal effect of this variable demonstrated that the farmers' probability of adopting the polyculture system increases by 24% when there are increased benefits given by polyculture system, ceteris paribus. The finding is consistent with Akudugu et al (2012) who pointed out that expected benefits from adopting influenced the decision to adopt the modern agricultural production technologies in the savannah agro-ecological zone of Ghana. The variable of cost of adoption was statistically significant at 1% and had a negative coefficient. It exhibits that if the adoption is expensive to the farmer, they are less likely to adopt the polyculture system and vice versa. The result of the marginal effect expressed that the farmers' probability of adopting the polyculture system decreases by 85% when there are increased costs of adoption, ceteris paribus. This finding is in line with Caswell et al (2001) stated that changes in farmers' investment costs influenced the farmers' decision to adopt the new system.

In terms of social capital variables, the group and training variables were significant and positively related to the likelihood for a farmer to adopt the polyculture system with a statistical significance of 10% and 5%, respectively. Results indicate that farmers are more likely to adopt the polyculture system if they are members of a farmers' group and have attended aquaculture training. Due to the fact that the education level of the farmers in the study area is lower, membership to farmers' groups and attendance of aquaculture training enable farmers to obtain information, informal knowledge and exchange ideas on polyculture system practices that encourage them to improve their experience and learning capability. Moreover, the findings are in line with the previous studies which revealed that farmers who have experience in membership of farmers' group and have attended training have higher tendencies to adopt new technologies (Mpogole 2013; Paul et al 2017; Amare & Simane 2017). Also, the marginal effect showed that when a farmer decides to become a member in a farmers' group and attends aquaculture training, the probability of a farmer to adopt the polyculture system increases by 28% and 19%, respectively.

Table 3

Logistic regression results of the factors determining polyculture system adoption

Variables	*Coef.*	*Std. err.*	*z-value*		*Marginal effect*	
Demographic factors						
Age	0.01	0.03	0.10		0.00	
Family size	0.66	0.21	3.13	***	0.15	***
Education level	0.22	0.11	2.01	**	0.05	**
Experience	-0.04	0.03	-1.26		-0.01	
Economic factors						
Expected benefits of adoption	1.06	0.43	2.46	**	0.24	**
Cost of adoption	-3.81	0.74	-5.12	***	-0.85	***
Social capital factors						
Group	1.25	0.70	1.79	*	0.28	*
Training	0.84	0.38	2.21	**	0.19	**
Extension	-0.13	0.19	-0.65		-0.03	
Constant	-3.40	1.29	-2.63	***		
Log-likelihood	-90.52					
LR Chi^2	164.75	***				
Pseudo R^2	0.48					
% predicted correctly	81.60					
Observations	250					

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

Conclusions. This study provides an understanding of the farmers' decision to adopt the polyculture system. The findings of this study are valuable for the government, private business and experts in recognizing what defines the farmers' decision-making behavior, in identifying the farmers who will most likely adopt the polyculture system and in determining the development trends, if adoption is to be attained in the future. Most of the results are logically consistent with previously observed studies in the literature. Education level and family size (demographic factors), expected benefits of adoption in economic factors, and members of a farmers' group and aquaculture training (social capital factors) increase the adoption of the polyculture system. Conversely, the cost of adoption is an obstacle to the adoption.

Results from the logistic regression model suggest that farmers with well-educated and larger families are more likely to adopt the polyculture system in the future. Consequently, based on this type of studies decision-makers could elaborate informed policies stimulating the adoption increase among the low-educated. Moreover, decision-makers should focus on implementing context-based informal education to complement the information and knowledge requirements. Another finding of this survey exhibits that the expected benefits of adoption influence the farmers' decision to adopt the polyculture system. Since the cost of adoption has a significantly negative relationship with the polyculture system adoption, the government and private business can cooperate in reducing the farmers’ constraints and creating incentive programs that focus on reducing the operational cost of the adoption as well as on designing insurance schemes motivating farmers to adopt the polyculture system. The study also demonstrate the crucial role of the social capital, therefore policy interventions promoting the farmers' group membership and the aquaculture training attendance could rise the rate of the polyculture system adoption.

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