CHOICE OF CLIMATE RISK ADAPTIVE MEASURES IN SHRIMP FARMING – A CASE STUDY FROM THE MEKONG, VIETNAM

Ngan Thi Thanh Le [a,b,*]; Claire W. Armstrong [a]

[a] *The Norwegian College of Fishery Science, UiT- The Arctic University of Norway, 9037 Tromsø, Norway.*

[b] *Faculty of Economics, Nha Trang University, Nha Trang, 650000, Vietnam.*

*** Corresponding author.**

ABSTRACT

Extreme climate events challenge the livelihoods of shrimp farmers worldwide. A comprehensive analysis of farmers' choices of adaptive measures is essential for developing approaches that can lessen the effects of these climate risks. This study presents the determinants that influence the choice of adaptive measures in response to two climate risks: drought and irregular weather, using a survey of 437 shrimp farmers in the Vietnamese Mekong region and applying a multinomial logit model. Five adaptation choices identified include changing feeding schedules/ stocking densities, changing water exchange schedules, water conservation, water treatments, and early harvesting. The results revealed that education, training, extension services, credit access, farm size, pond numbers, and the farmers' perception of drought and irregular weather are the main factors influencing farmers' choices of adaptive measures. Intensive and extensive farmers chose different adaptations to climate risks, with the former applying various measures while the latter chose to change water exchange schedules. The conclusions bring policy implications concerning how to cope with climate risks.

Keywords: climate risks, adaptation, shrimp aquaculture, multinomial logit model, Vietnam.

Email addresses: nganltt@ntu.edu.vn (Ngan Thi Thanh Le), claire.armstrong@uit.no (Claire W. Armstrong)

ORCID

Ngan Thi Thanh Le https://orcid.org/0000-0003-2978-6505

Claire W. Armstrong http://orcid.org/0000-0002-1837-9165

1. Introduction

There has been rapid growth in Vietnamese white-leg shrimp (*Litopenaeus vannamei*) farming in recent years (Nguyen et al., 2019; Shinji et al., 2019). The broader importance of shrimp aquaculture development is underlined by the considerable inclusion in the shrimp value chain of rural, household-based extensive and intensive production. This significant trend contributes to employment and income, alleviating poverty while securing national exports and foreign exchange (Phillips et al., 2007). However, increasing climate variability and complexity seriously challenge shrimp culture growth, severely impacting production yields and threatening seafood supply (FAO, 2016).

1.1 Climate issues threatening Vietnamese shrimp aquaculture in the Mekong region.

Vietnam is one of three nations (including Egypt and Thailand) with the highest vulnerabilities regarding brackish water production in the face of climate-driven change (FAO, 2020). In addition, the Mekong Delta (MKD) region of Vietnam, which produces 60-75% of the total national shrimp production (Nguyen, 2017), suffered in 2016 its worst drought in 90 years (FAO, 2016). Due to natural disasters and unstable weather, there have been substantial losses in Vietnamese shrimp production in recent years (Nguyen et al., 2021). Drought and saline intrusion are frequent critical issues for the Mekong aquaculture and require appropriate response measures (Sebastian et al., 2016).

In shrimp culture, NACA (2012) and Quach et al. (2015) reported that drought and irregular weather are prominent climate risks, leading to massive losses for shrimp production in the Mekong region. NACA (2012) and Quach et al. (2015) stated that drought implies high temperatures and lack of precipitation for a long per, seriously affecting shrimp aquaculture. Irregular weather (e.g., sudden changes in temperature and heavy rainfall) occurs unpredictably, leading to substantial water temperature and quality variations, bringing stress and a greater chance of shrimp disease.

1.2 Motivation for this study

Increasingly, local agricultural and shrimp-producing communities in coastal regions have become aware of climate impacts and the severity of climate events (e.g., increasing temperature, sea-level rise, salinity intrusion) (Halder et al., 2012; Hasan & Kumar, 2020; Quach et al., 2017). Consequently, shrimp farmers' risk perception is one of the critical drivers for their risk management responses or adaptation (Shameem et al., 2015). Such adaptation is an actual adjustment in practices, processes, capital, or decision changes in response to observed or expected climate risks to reduce vulnerability or enhance resilience (Adger et al., 2007).

However, significant barriers hinder the implementation of adaptation strategies and perceptions (Adger et al., 2007), and adaptation strategy choices contributing to mitigating climate risks vary amongst farmers (Arunrat et al., 2017). Furthermore, a lack of understanding regarding farm households' perceptions of weather conditions may lead to ineffective policies incentivizing individual and group adaptation measures (Alam et al., 2017). Arunrat et al. (2017) stated that policy support is crucial for enhancing agricultural farmers' adaptive capacity and adequate preparation concerning expected climate change, which can also be claimed to be the case for the aquaculture sector.

There are a large number of studies on climate adaptation in terrestrial farming worldwide, including in Asia. For instance, Dang et al. (2019) and Singh (2020) synthesize a substantial number of papers regarding factors influencing agricultural farmers' climate change adaptation globally, while Shaffril et al. (2018) focus on similar practices and strategies in Asian countries. Galappaththi et al. (2020) discussed three adaptation strategies for applying water quality management and changing farming practices in aquaculture. In addition, several international climate adaptation projects (Abery et al., 2009; Muralidhar et al., 2012; Joffre et al., 2019; NACA, 2011, 2012; Shelton, 2014) provide general recommendations regarding adaptation to climate risks in shrimp farming in Vietnam and India. However, equivalent academic studies identifying the determinants of farmers' adaptation choices to climate risks are limited in WLS culture (see Shameem et al., 2015; Seekao & Pharino, 2016, and Do & Ho (2022) for studies of Bangladeshi, Thai, and Vietnamese shrimp farming). Therefore, our study collected farm-level data to investigate these choices and provide quantitative input to support Vietnamese shrimp sector policymaking. We surveyed 437 *Litopenaeus vannamei* shrimp farms from March to August 2017 in two provinces (Bac Lieu and Ca Mau) of Vietnam's Mekong region.

Climate risk perception is inherently a "*subjective judgment that people make about the characteristics and severity of a risk*" (Shukla et al., 2019, p.822). Farmers' perceptions are "*subjective judgments which inform appropriate reactions, based on explicit and tacit knowledge about the characteristics and severity of risk*" (Soubry et al., 2020, p.211). Based on subjective perceptions after experiencing extreme climate occurrences in recent years and assessing the climate risk severity levels concerning cost increases, interviewed shrimp farmers selected their preferred adaptive choices for coping. Amongst the reported ten identified adaptive measures, we focus on the most common five choices: (1) change in feeding schedules/ stocking densities, (2) change in water exchange schedules, (3) water conservation, (4) water treatments, and (5) early harvesting. These adaptive measures are autonomous adaptations adopted by shrimp farmers.

Multinomial logit (MNL) is a common method employed for assessing factors influencing agricultural farmer adaptation choices to climate risks (Addisu et al., 2016; Alam, 2015; Alauddin & Sarker, 2014; Arunrat et al., 2017; Chu et al., 2010; Deressa et al., 2009; Gbetibouo, 2009; Gbetibouo et al., 2010; Gebrehiwot & Van Der Veen, 2013; Sarker et al., 2013), but has to our knowledge hardly been applied for similar studies in aquaculture. Though there exists quantitative analysis of shrimp aquaculture (Do & Ho, 2022; Joffre et al., 2019), ours aim to employ MNL for assessing drivers affecting farmer adaptation choices using Vietnamese shrimp farm-level data.

1.3 Objective of the study

The research objectives include the following:

1) Identify shrimp farm-level adaptive measures to climate risks in the Mekong,

2) Analyze potential crucial explanatory variables (socio-economic factors; farm characteristics, knowledge sharing, service accessibility, and farmer's perception of climate risks that drive farmers' adaptation choices in different farming production systems, i.e., intensive and extensive shrimp farming, and

3) Provide knowledge emanating from our results to assist Vietnamese and other countries' shrimp farmers and policymakers in understanding shrimp practices and adaptation choices better.

Section 2 presents Materials and Methods with subsections on the formulation of the MNL model, the study design, farmers' choice of adaptive measures in shrimp farming, and potential explanatory factors driving the adaptation choices. Section 3 highlights results evaluating determinants affecting farmers' adaptation choices. Finally, sections 4 and 5 include discussions and concluding remarks.

2. Material and Methods

This section elaborates on the study design, the MNL model, adaptive measure choices, and key determinants affecting farmers' adaptation.

2.1 Study design

Data collection started with reviewing the adaptation choice literature in agri- and aquacultural sectors, followed by field trips to aquaculture farms, focus group discussions (FDG), and the implementation of a pre-test survey. The final step was face-to-face interviews with shrimp farmers. Farm visits provided a better understanding of shrimp practices. FGD, with 6-8 participants in each province, was used to generate detailed information on farmers' coping strategies for climate risks and develop the final questionnaire before implementing the survey. FGD participants were staff members who worked at provincial aquaculture departments, local shrimp farmers, technicians, and staff from the extension services department. In addition, members of the FGDs provided lists of shrimp farmers representing a cross-section of shrimp farming communities. Thus, we apply an extensive survey that captures many responses. The twenty pre-test samples in each province were useful for improving the questionnaire design. The final survey collected data from face-to-face interviews with 437 shrimp farmers using a structured questionnaire[1], identifying farmers' perceptions regarding the severity level of CR occurrences in shrimp farming, socio-economic factors, farming characteristics, and farmers' adaptive measures when perceiving their impacts.

2.2 Method

The multinomial logit model (MNL) allows us to estimate the shrimp farmer's selection of the most preferred adaptation across more than two choices. The *i*th farmer will choose the *j*th adaptive measure that gives him/her a greater utility U_{ij} than other k options, described as:

$$U_{ij}\left(\beta_j X_i + \epsilon_j\right) > U_{ik}(\beta_k X_i + \epsilon_k), \qquad k \neq j \tag{1}$$

where X_i describes a vector of explanatory variables influencing adaptation choices, β_j and β_k are estimated parameters, with ϵ_j and ϵ_k being the error terms. MNL also allows the estimation of the probability of choosing each choice option in the set of explanatory variables (Greene, 2003).

The MNL includes the assumption of independence of irrelevant alternatives (IIA), with the basis of this assumption being that independent and homoscedastic disturbance terms of eq. (1) are required to obtain unbiased and consistent parameter estimates.

[1] The survey consists of (1) the information of climate factors that shrimp farmers perceived in their most recent crop, (2) farmer's adaptive measures to these climate risks in shrimp practices, (3) biosecurity applications, (4) information on farming characteristics (e.g., land uses, culture period), and (5) disease issues in shrimp farming.

The probability of observing the jth outcome for a given X is formulated as:

$$\text{Prob}(y = j|X) = \frac{\exp(\beta_j X)}{1 + \sum_{k=1}^{J} \exp(\beta_j X)}, \qquad j = 1, \ldots . J \tag{2}$$

Where y denotes adaptive measure categories. $P(y = j|x)$ defines the response probability, which we know once the probabilities for j = 1, . . ., J are determined. The sum of the probabilities equals one.

As Gebrehiwot & Van Der Veen (2013) state, the estimated parameters from equation (2) only provide information on how the explanatory variables influence the adaptation choices but do not determine the magnitude of each choice. Therefore, we also assess the marginal effects or marginal probabilities, providing the expected change in probability of a given a choice to a unit change in the explanatory variables. (Greene, 2003). Marginal effects of the explanatory variables are shown as:

$$\frac{\partial P_j}{\partial X_k} = P_j \left(\beta_{jk} - \sum_{k=1}^{J-1} P_j \beta_{jk} \right) \tag{3}$$

In this paper, farmers' adaptations are autonomous in the sense that the farmers cover the costs of adaptive measures, though we do not assess the actual costs here. Instead, we employ the concept of farmers' perception of climate risks as a critical factor shaping farmers' choice of adaptation. Individual adaptation strategies are considered potential solutions to mitigate the negative impacts of environmental issues. The next part briefly elaborates on the classification of adaptation strategies.

2.3 Farmer's Choices of adaptive measures in shrimp farming

In the literature, many agricultural studies identify farmer intention, perception, and choice of adaptation strategies supplying measurement of several specified adaptive choices to climate change (Abidoye et al., 2017; Arunrat et al., 2017; Deressa et al., 2009; Gebrehiwot & Van Der Veen, 2013; Maya et al., 2019; Sarker et al., 2013), Within the shrimp aquaculture field, Ahmed & Diana (2015) and Shameem et al. (2015) suggested several adaptive measures to protect Bangladeshi shrimp cultures such as the construction of earthen dams, higher dikes, increased embankment height, deeper ponds, as well as fencing and netting around shrimp farms for flood management, use of medical resources and the application of liming. Seekao & Pharino (2016) mentioned nets surrounding ponds and dykes enclosing ponds when flooding occurs in Thailand. In addition, these authors focus on farmers operating in vulnerable areas with challenging financial circumstances, suggesting low-cost options such as alternative crop patterns and harvest seasons. In Vietnamese shrimp farming, Abery et al. (2009) identify adaptations to climate change such as securing better water quality through maintaining pond water levels, planting trees on pond dykes to provide shade or stability, listening to radio weather warnings, harvesting shrimp prior to the arrival of severe storms, developing better crop calendars for storm impacts, reducing stocking density, culturing new species, practicing polyculture, and using smaller ponds for minimizing the impacts related to irregular seasonal changes. Do & Ho (2022) found that three adaptation strategies (dikes upgrade, lining plastic sheets, and settling ponds) contribute to higher productivity in shrimp farming. In addition, NACA (2012) indicates several adaptation measures practiced by shrimp farmers to mitigate climate change, such as changing the surface water, making ponds deeper and ditches wider, and increasing dike height. Shelton (2014) presents the Lower Mekong Basin project, which provided recommendations to increase cooperation and communicate lessons learned as relevant adaptive measures. Furthermore, these authors suggested training related to improving culturing techniques. Pilot shrimp farming models have been developed to enhance management capacity for upgrading production, accessing the market, mitigating disease-related risks, and improving water quality (Dung, 2017). Joffre et al. (2019) studied various disease, market, and climate risk perceptions. These authors found that such risk perceptions, farmer clustering, and network interactions positively influenced Vietnamese shrimp culture adaptive practices, particularly regarding water quality management, disease, and feed input controls.

Reviewing the shrimp culture literature, we collated lists of climate occurrences and relevant adaptive measures from the farm to government policy levels. However, to date, few aquaculture studies assess determinants driving farmers' adaptation choices to climate risks at the farm level in Vietnam (see however (Nguyen, 2017), especially for *vannamei* shrimp, something we attempt to remedy here.

The specific adaptation choices in shrimp farming are employed from the reviewed literature and focus group discussions in the study of Le et al. (2022). Based on this, many different adaptive measures were listed in the survey as possible responses to climate risks. The farmers ticked all measures they had applied and added alternative measures used. Based on this, we chose the ten most relevant adaptation options in Table 2. Shrimp farmers apply adaptation actions based on different aquaculture technologies for managing pond water quality, as presented in Table 1. These measures contribute to maintaining shrimp health and coping with potential climate, production, and environmental risks.

Table 1 Farmers' adaptive measures to perceived climate risks.

No	Adaptive measures	Interpretation of measures
1	Change feeding practice schedules	This measure includes a change in feeding schedules and the amount of feed used in a shrimp crop. This option provides cost savings and adjusts timely and appropriately the amount of feed during extreme climatic events (e.g., drought or heavy rain).
2	Change distribution strategies	This option involves flexibility in distributing farm output in the shrimp supply chain. Seeking alternative markets to sell shrimp is an option for farmers when harvested shrimp size cannot meet the purchasers' demands or contracts. This option helps to attain cost compensation when extreme climatic events occur.
3	Early harvesting	Harvesting early aims to save the shrimp crop when faced with expected severe climatic events or water cross pollution, thereby reducing

		vulnerability to disease. Farmers adjust the stocking period to protect sensitive growth stages impacted by climate variability.
4	Adjust stocking densities	Farmers can adjust the number of shrimps in the pond in the current or next crop depending on their production system and the kind of extreme climate event (e.g., drought, irregular weather, prolonged rain). The reduction in stocking density can help manage water quality during climate occurrences.
5	Culturing new species	This measure includes the choice of changing to new species of aquatic animal culture. For example, farmers may consider the gain and loss of continuing to culture white leg shrimp during prolonged climate occurrences, or switching to another species (e.g., giant tiger shrimp) that is more robust to the climate occurrence.
6	Switch to another type of production system	A possibility here is to change from monoculture to polyculture. For example, the combination of different species such as shrimp – fish, shrimp – crab, rice – shrimp, or mangrove- shrimp are production systems that farmers use to adapt to climate change.
7	Change water exchange scheduling	This strategy of planning and reorganizing water exchange in order to make appropriate decisions on timing for water exchange to manage the pond water level.
8	Water conservation	Water conservation is displayed in many forms, for instance, low or zero water exchange, or recirculation water systems. In addition, using reservoir or sediment ponds for water stocking allows farmers to avoid or reduce water shortage and cross pollution.
9	Water treatment	This measure includes the application of lime or chemicals in ponds to maintain the water conditions needed for stabilizing the growth stages of shrimp and/or water pumping and filtering when pond water levels are insufficient during prolonged drought conditions.
10	Pond renovation	This option includes upgrading bank/dyke height, deeper ponds, etc., for pond renovation purposes. Such upgrading may contribute to better biosecurity systems for pond management.

Sarker et al. (2013) and Alauddin & Sarker (2014) suggested that an MNL model with more than ten choice options could be expected to fail to produce statistically significant results, recommending a lumping together of several options. We found this to be the case when including all options in Table 2 in the MNL model. We, therefore, adopted a reduction in choice options by merging closely related measures into single groups. For example, we combined two choices, a change in feeding schedules and stocking density adjustment. We renamed a change in feeding schedules/ stocking density since farmers simultaneously practiced these two measures. In addition, due to a meager selection by farmers (less than 10%), we excluded five choices from our adaptation choice categories: switching to another production system, culturing new species, changing the distribution channel, and pond renovation. The final five-choice options are specified as follows:

$$y = \begin{cases} 1 = \text{Change in feeding schedules/ stocking density} \\ 2 = \text{Change in water exchange schedules} \\ 3 = \text{Water conservation} \\ 4 = \text{Water treatment} \\ 5 = \text{Early harvesting} \end{cases}$$

Figure 1 shows the farmers' most preferred adaptation choices: change in water exchange schedules (33% of farmers), followed by water treatment (27%). Water conservation and early harvesting are both chosen by 14 % of the farmers, while the lowest percentage of farmers (12%) applied change in feeding schedules/ stocking density.

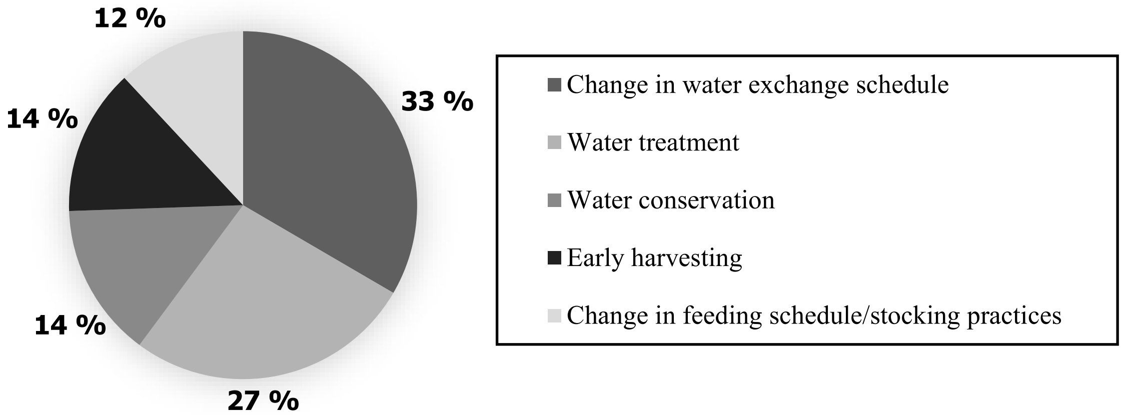

Fig.1. Farmer's choice of adaptive measures (%)

2.4 Explanatory variables explaining adaptation choices to climate risks.

The agricultural studies applying MNL assessments of adaptation measures draw attention to many internal and external factors affecting farmers' choices. This study extracts explanatory variables from an extensive literature review (see Table A1 - appendix A) and FGD. Therefore, we grouped potential explanatory variables into five classes: socio-economic factors; farm characteristics; knowledge sharing; service accessibility; and farmers' perception of climate risks. Socioeconomic factors include experience, education, number of family members, and farmers' income. Based on the literature, we hypothesize that these factors may positively or negatively impact farmers' choices.

Regarding farm characteristics, we include two factors related to disease and governmentally planned areas in the list of explanatory variables suggested in the literature. These were mentioned FGD as some of the main factors determining farmers' responses. Shrimp farms that experienced disease earlier can be expected to actively select farming measures for managing the impact of climate risks to limit the spread of disease. Planned area defines who belongs to governmentally accepted planned areas for shrimp aquaculture. Those who belong to governmentally planned areas gain from the advantages of irrigation systems (dyke and dam construction) and other development (electricity, roads) provided by the local government, creating more efficient preparation for taking active measures to adapt to climate risks. Based on the literature, we expected factors related to farm characteristics might work both ways affecting farmer adaptation choices.

This study suggests that farm area and pond numbers can be used to classify extensive and intensive shrimp farming production systems. Farms with large areas and few ponds represent extensive farming, i.e., more low-technology farming, while intensive farmers operate high-tech small farming areas with many ponds. Extensive shrimp farming often involves larger areas with low-technology operations, including feed provided by the natural environment. Intensive farming favors smaller areas and compounds using many inputs, such as capital, labor, feed, chemicals, seed, and high stocking density. Intensive farms of less than 0.5 hectares can harvest large yields with a short crop (2-3 crops/year), bringing substantial income to shrimp farmers. The production system is represented by a dummy variable (intensive equals one and extensive production system equals zero), highly correlated with farm area and pond numbers. The different degrees of extensive and intensive farming are expected to co-exist also into the future.

We assess the role of knowledge-sharing via farmer clusters and training program attendance and expect them to shape farmers' adaptation regarding climate risks positively. Farm clusters define membership of small farmer groups (neighbors in the same areas) or shrimp associations (e.g., Association of Seafood Exporters and Producers - VASEP) and cooperatives (e.g., at the commune level). Joffre et al. (2019) identify farmer clusters as playing a significant role in adaptive behavior by providing shrimp business networks and information sharing. They indicated that social interactions could shape risk perception. We expected social interaction through participation in farmers' clusters to increase awareness of climate risks, improving the chance of farmers choosing adaptive measures. Though training programs have failed to significantly impact farmers' adaptation choices in the literature (Arunrat et al., 2017), we keep this variable in our estimation due to suggestions from FGD and reviewed projects presented in section 2. We expected participation in training programs could increase the sharing of climate-related information and lessons learned from success stories of adopting adaptive measures and provide up-to-date technological know-how in shrimp farms, potentially encouraging further adaptation.

Regarding service accessibility, extension services are understood as providing technical visits offered by provincial or local aquaculture departments and private companies, guiding shrimp farmers with water treatment, disease control, and farming management activities. Via such technical visits, farmers can receive information regarding CR warnings, water sample testing when climate risks and disease appear, or specific advice for constructing farm infrastructure, pond design, and water treatment systems, should farmers wish to convert to intensive/super-intensive systems. Therefore, we expect extension services to enhance the farmers' response to climate risks. In addition, credit access is a dummy coded for those who receive a credit via official bank loans, potentially contributing to farmers' adaptation to climate risks.

Our analysis regarding farmers' perception of climate risks includes drought and irregular weather. We found these to be the two most identified climate risks in our Mekong shrimp farmer sample (see Figure 2).

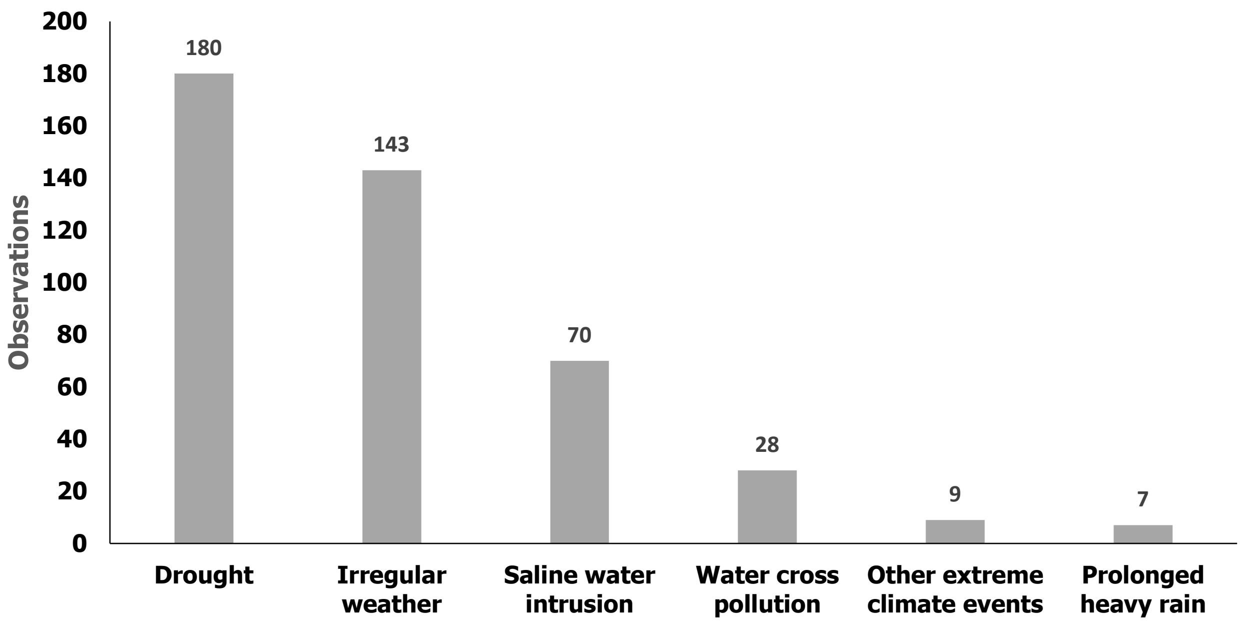

Fig. 2. Farmer's perception of different kinds of extreme climate events occurring in shrimp farming

In addition, we also asked the shrimp farmers to assess the severity of these two climate risks using a seven-point Likert scale[2]. The degree of severity is defined in relation to an

[2] We define a seven-point Likert scale consisting of -3: Extremely positively impacted (cost reduction of more than 50%), -2: Major positively impacted (cost decline between 10%-50%), -1: Minor positive impact (costs decline by less than 10%), 0: No consequence, 1: Minor negative impact (costs rise by less than 10%), 2: Major negative impact (costs rise between 10%-50%), 3: Catastrophic/ extremely negative impact (costs rise by more than 50%).

increase in farm cost. Farmers' perceptions of climate risk factors are dummies in our analysis, generated from climatic risks interacting with the different degrees of increased costs. We expected farmers' perceptions of climate risks to affect adaptation choices positively, i.e., the expectation of higher costs would increase adaptation but found that adaptative measures were mainly carried out in relation to drought and irregular weather. Therefore, we employed farmers' perceptions of drought and irregular weather in the final model estimation.

Table 2 describes the fourteen explanatory variables, organized into five classes for testing the influence on farmers' adaptation choices. Most are dummy variables (yes/no), while others are continuous variables related to socioeconomic factors and farm characteristics (farm size in hectares and pond numbers).

The average working experience of farmers in the shrimp business was 14 years, and the average education level was a primary school. In our sample, only 21% are members of farmer clusters, while nearly 50% of the farmers participated in training courses held by provincial or local governments. In addition, 76% of farmers belonged to a planned area, and 19% experienced shrimp disease in their crops. We found that a small proportion of the sample of farmers have access to extension services and official bank loan credit (20% and 26%, respectively). In the sample, 36% and 29%, respectively, perceived that drought and irregular weather phenomena were severe. In the following, we employ the MNL model to determine how the effects of farmers' perceptions of drought and irregular weather, and other explanatory factors impact farmers' adaptive measure choices.

Table 2 Data description

	Factors	Description	Expected sign	Var. type	Mean	S. E	Min	Max
	Socio-economic factors							
1	Experience of farm owner	Number of years in shrimp business	+/-	In number	14.29	9.49	1	53
2	Education of farm owner	Number of schooling years	+/-	In number	7.32	3.92	0	22
3	Owner household size	Number of family member	+/-	In number	4.27	1.20	1	13
4	Farm income	Total shrimp farm income (million VND/crop)	+/-	In number	10.97	1.48	5	15
	Farm characteristics							
5	Farm area	Total shrimp area per hectare	+/-	In number	1.05	1.18	0.1	8.0
6	Pond numbers	The number of ponds used for culturing shrimp	+	In number	1.42	0.88	1	7
7	Planned areas	Dummy variable	+	1: Yes; 0: No	0.76	0.43	0	1
8	Disease risk	Dummy variable	+	1: Yes; 0: No	0.19	0.40	0	1
	Knowledge sharing							
9	Training attendance	Dummy variable	+	1: Yes; 0: No	0.47	0.50	0	1
10	Farmer cluster	Dummy variable	+	1: Yes; 0: No	0.21	0.41	0	1
	Service accessibility							
11	Extension services	Dummy variable	+/-	1: Yes; 0: No	0.21	0.41	0	1
12	Credit access	Dummy variable	+/-	1: Yes; 0: No	0.26	0.44	0	1
	Farmer's perception regarding climate risks							
13	Drought	Dummy variable	+/-	1: Yes; 0: No	0.36	0.48	0	1
14	Irregular weather	Dummy variable	+/-	1: Yes; 0: No	0.29	0.46	0	1

Notes: *Number of observations is 437 but only 383 farmers reported income.*

3. Results

In this section, we present the results of the MNL models, but first, we describe the farmers' chosen adaptation options[3].

3.1 Multinomial logit model for choice of adaptive measures

Table 3 presents the Hausman test for the IIA assumptions. The null hypothesis (H_o) implies that the odds ratio for each specific pair of outcomes is independent of other alternatives or that deleting outcomes should not affect the odds among the remaining outcomes.

Table 3 Hausman test of IIA assumption in the MNL model for shrimp farmer's adaptation choices.

Omitted variables	$\chi 2$	DF	$p > \chi 2$	Decision
Change in feeding schedules /stocking density	-161.291	45	1.000	Accept Ho
Change in water exchange schedules	27.195	45	0.983	Accept Ho
Water conservation	2.636	45	1.000	Accept Ho
Water treatment	-4.168	45	1.000	Accept Ho
Early harvesting	-0.694	45	1.000	Accept Ho

Note: DF is degree of freedom

[3] Bivariate Probit models were also applied for robustness checks, and the results do not differ to any significant degree. The choice of change in water exchange schedules is used as the base in this modeling. No multicollinearity among the explanatory variables was found in the estimation.

The omitted variables achieved p-values of 1.000, indicating that the MNL satisfies the asymptotic assumptions of the Hausman test (Sarker et al., 2013), and we can accept the null hypotheses. We conclude, therefore, that the IIA assumptions are not violated, and the MNL model specification is appropriate for modeling shrimp farmers' adaptation choices to climate risks (Hausman & McFadden, 1984). Table 4 illustrates the empirical results of the MNL model with the base adaptation outcome (reference category) being a change in the water exchange schedules, the most chosen adaptation option (33 % of total surveyed farmers), simile ar to the study of Alam (2015).

Table 4 Parameter estimates of MNL adaptation choices.

Factors	Base outcome: Change in water exchange schedules							
	Feed schedules and stocking density		Water treatment		Water Conservation		Early Harvesting	
	Coef	p level	Coef	p level	Coef	p level	Coef	p level
Socio-economics factors								
Experience	0.022	0.413	-0.063*	0.081	0.020	0.375	-0.054*	0.098
Education	-0.023	0.696	0.152**	0.015	0.105**	0.027	0.018	0.779
Family size	-0.039	0.812	0.113	0.563	-0.199	0.188	-0.138	0.474
Income	-0.108	0.550	-0.172	0.409	0.128	0.429	-0.184	0.336
Farm characteristics								
Farm area	-1.041***	0.000	-1.362***	0.000	-1.109***	0.000	-0.569	0.044
Pond numbers	0.820	0.015	0.856**	0.019	0.754**	0.013	0.530	0.155
Planned area	0.404	0.528	-1.058*	0.083	-0.243	0.618	-1.472**	0.013
Disease occurrence	-1.120	0.119	-0.974	0.193	-0.480	0.361	-0.468	0.508
Knowledge sharing								
Training program attendance	-0.560	0.228	-1.702***	0.006	-0.683*	0.089	-0.008	0.989
Farmer cluster	-0.874	0.228	-1.222	0.154	-0.434	0.454	0.635	0.377
Service Accessibility								
Extension services	0.420	0.587	1.218	0.118	1.802***	0.003	0.040	0.962
Credit access	-0.474	0.288	-2.206***	0.002	-0.778*	0.051	-0.094	0.861
Farmer's perception to climate risks								
Drought	0.024	0.956	0.816	0.225	-0.322	0.410	-3.178***	0.004
Irregular weather	1.664**	0.013	2.806***	0.000	0.969	0.110	1.500**	0.021
Constant	-1.206	0.569	-0.791	0.747	-2.673	0.153	2.656	0.235
Log likelihood	-399.225							
Pseudo R2	0.2885							
LR chi2	323.71							
Observations	372							

Note: ***, **, and * imply statistical significance at 1, 5, and 10 % probability level, respectively.

The coefficients and p-values in Table 4 indicate the likelihood and statistical significance of farmers selecting one of the remaining adaptation choices compared to the base. Sixty-five farms contained insufficient data and were removed from the MNL adaptation choice estimation, resulting in 372 observations. Positive coefficients imply that a unit increase in explanatory variables will increase the likelihood of farmers choosing the appropriate adaptation compared to the reference adaptation. More specifically, education, extension services, pond numbers, planned area, and perception of climate risks (irregular weather and drought) are all statistically significant predictors driving the choice of other adaptation alternatives compared to the reference option. An increase in extension service accessibility is a factor that influences the choice of water conservation ahead of changes in the water exchange schedules. An increase in one year of schooling increases the likelihood of choosing water treatment and water conservation.

Regarding shrimp farm characteristics, all coefficients of farm area in the MNL model are negative and highly significant (1%), while the pond number coefficients are significant (from 5 to 10%) positive. Large pond numbers are a potential marker for intensive farms, while extensive farms have large land areas; these results imply that intensive farmers seem to adopt a broader set of adaptive measures relative to the base adaptation. In contrast, extensive farmers tend to stick to the base adaptation of water exchange schedule changes. The farmers who perceived irregular weather are more likely to adopt adaptations related to a change in feeding schedules/ stocking practices, water treatment, and early harvesting than the reference choice. Compared to the base, we failed to show a statistically significant relationship between disease occurrence, family size, income, farmer clusters, and farmer adaptation choices.

In contrast, statistically significant negative coefficients appear for experience, training program attendance, credit, and planned area, implying an increase in these variables reduces the likelihood of farmers choosing other adaptations than a change in water exchange schedules (the base category). More specifically, farmers who have more years of experience or training program attendance are more likely to choose the base adaption choice than selecting water treatment. Similarly, credit access negatively impacts the choice of reference option compared to water treatment or water conservation. A striking finding was the highly statistically significant probability of choosing the reference option ahead of pond renovation amongst farms in planned areas.

We present marginal effect values of the MNL model in Table 5 to interpret the expected change in probability of each adaptation choice for a unit change in the explanatory variable.

Table 5 Marginal effects from MNL adaptation choices

	Feed schedules and stocking density		Water exchange Schedules		Water Treatment		Water Conservation		Early harvesting	
Factors	dy/dx	P level	dy/dx	P level	dy/dx	P level	dy/dx	P level	dy/dx	P level
Socio-economic factors										
Experience	0.003	0.342	-0.001	0.825	-0.005**	0.034	0.006	0.165	-0.004*	0.065
Education	-0.012*	0.087	-0.015	0.114	0.008**	0.038	0.021**	0.013	-0.002	0.603
Family size	0.007	0.738	0.026	0.336	0.014	0.234	-0.043	0.155	-0.004	0.729
Income	-0.019	0.410	-0.001	0.977	-0.012	0.300	0.046	0.145	-0.013	0.250
Farm characteristics										
Farm area	-0.056	0.101	0.231***	0.000	-0.045**	0.017	-0.141***	0.002	0.011	0.522
Pond numbers	0.053	0.136	-0.165***	0.007	0.024	0.176	0.087*	0.074	0.001	0.958
Planned area	0.105	0.194	0.063	0.497	-0.061*	0.083	-0.016	0.862	-0.090**	0.033
Disease occurrence	-0.113	0.230	0.151	0.131	-0.036	0.421	-0.003	0.978	0.000	0.995
Knowledge sharing										
Training program attendance	-0.016	0.786	0.150**	0.047	-0.088**	0.027	-0.078	0.321	0.033	0.346
Farmer cluster	-0.091	0.293	0.113	0.339	-0.062	0.207	-0.030	0.766	0.070	0.106
Service accessibility										
Extension services	-0.069	0.436	-0.262**	0.035	0.028	0.480	0.358***	0.000	-0.055	0.235
Credit access	0.009	0.870	0.169**	0.023	-0.119***	0.007	-0.091	0.258	0.031	0.357
Farmer's perception to climate risks										
Drought	0.053	0.382	0.090	0.205	0.078*	0.061	-0.015	0.854	-0.206***	0.000
Irregular weather	0.124*	0.095	-0.303**	0.008	0.132***	0.007	0.008	0.938	0.039	0.253

Notes: ***, **, and * are significant at 1, 5, and 10 % probability levels, respectively.

As shown in Table 5, we found that more than four different input factors explain some adaptive measures. For example, the adaptation choices of water exchange schedules, water treatment, and water conservation respond to many factors (e.g., education, training program attendance, extension services, having credit access, farm area, and pond numbers, and perception of irregular weather) and are highly statistically significant. In contrast, farmers' education and irregular weather determine the choice of change in feeding schedules/ stocking density. The choice of early harvesting and change in feeding schedules/ stocking density is not impacted by the farming production system – extensive and intensive - captured by the two variables related to farm area and pond numbers. Water conservation and water treatment are, for the most part, similarly driven by the predictors. For instance, education plays a positive role, motivating the probability of choosing these adaptation options, while farm area plays a negative role, reducing the likelihood of selecting these choices.

Most explanatory factors have positive and negative effects, varying across the adaptation options. For example, service accessibility and knowledge sharing significantly impact two choices of methods. More specifically, farmers with access to extension services have a higher probability of conserving water and a lower probability of changing water exchange schedules. However, those participating in training programs are likelier to adopt water exchange schedules and less likely to apply water treatment.

Several factors have surprisingly different impacts on the same adaptation option. For example, socio-economic factors, such as experience and education, affect water treatment adaptation negatively and positively at 5% statistical significance, respectively. Similarly, within service accessibility, extension services and credit access have opposite effects on the change in water exchange schedules, at 5 % statistical significance.

Four factors, farmer clusters, family sizes, income, and disease occurrence, have no significant effect on adaptation choices. Thus, no factors have purely positive effects, but perhaps surprisingly, two factors have purely adverse significant effects: Experience and planned areas, each negatively influencing the same two adaptation options, water treatment and early harvesting. In contrast, several factors (extension services, credit access, farm area, pond numbers, and perception of climate risks - irregular weather and drought) are statistically strong predictors that positively drive farmer choice regarding several adaptive measures at a 1% or 5% significance level.

Table 5 reveals that there may be a significant difference in the choice of adaptation methods between intensive and extensive farms. As stated earlier, based on the typical differences between intensive and extensive farms regarding pond numbers and farmland, the results indicate that extensive farmers tend to adopt changing water exchange schedules. In contrast, intensive farmers are more likely to select water conservation. In the following section, we discuss factors that significantly increase the farmers' choice of adaptation methods and provide policy implications for developing appropriate approaches to lessen the effects of climate risks in shrimp farming.

4. Discussion

In the following, we assess the different factors that impact on adaptation choices for the intensive and extensive farmers.

4.1 Socio economics factors

Educational attainment and experience are socio-economic factors that play important roles in affecting positive adaptation choices, a result also noted by Do & Ho (2022). Education potentially enhances the farmers' desire and ability to select relevant adaptive water treatment and conservation measures. Water treatment and conservation require sound theoretical and practical knowledge and technical prowess, which can be conveyed via more years of schooling. Hence, encouraging farmers to go to school can increase knowledge and awareness for coping with climate risks. In contrast, farmers with less experience tend to choose early harvesting and water treatment when perceiving climate risks.

4.2 Farm Characteristics

We found that increased farm size increased the probability of changing water exchange schedules. In contrast, a unit decrease in farmland increases the probability of adopting water treatments and conservation. In addition, an increase in the number of ponds increased the likelihood of choosing water conservation, while a decrease in pond numbers increased the probability of changing water exchange schedules. Our findings are different from the suggestions of Joffre et al. (2019). Their results indicated that having more shrimp ponds affected farmers' adoption of water treatment measures and mentioned that smaller shrimp farms tended to adopt feed-input practices. As noted earlier, land area and pond numbers are in this study assumed to imply differences in production systems, extensive and intensive, respectively, and our findings indicate significant differences in farmer adaptation choice across these two technologies. We found that intensification made water conservation more likely, while extensive farms with greater farm size and fewer ponds have a higher probability of changing water exchange schedules. In our research sites, water conservation and water exchange are preferred since Bac Lieu and Ca Mau are coastal provinces with the advantage of a large density of river branches, providing irrigation for shrimp aquaculture. In the Mekong region, extensive farms have proximity to the coast or Mekong estuaries/rivers, allowing the employment of water exchange following the tidal system.

In contrast, intensive farms primarily operating further inland may face greater water pumping costs. Therefore, water conservation is a good option for intensive farmers to cope with climate risks. In addition, we found that farmers whose farms do not belong to planned areas assigned by local authorities are more likely to choose adaptive measures regarding early harvesting and water treatment when they perceive the severity of climate risks.

4.3 Knowledge sharing

We found a significant contribution of training program attendance influencing farmers' adaptation choices to climate risks, as previously suggested in development projects in Vietnam (NACA, 2011). For example, farmers with such attendance are more likely to choose water exchange schedule adaptation and have a low probability of choosing water treatments. In addition, recommended crop calendars, CR information, and environmental issues can easily be transferred to shrimp farmers via training programs.

4.4 Service accessibility

Gebrehiwot & Van Der Veen (2013) suggested that farmers who interacted with extension agents to a greater degree carried out adaptation responses to climate change. In this study, extension services or technical visits positively influence farmers' choice of water conservation rather than water exchange schedules. Furthermore, via technical assistance, farmers may consider the appropriate form of water conservation (restoring water or installing water circulation systems) based on their farming infrastructure and budget for coping with climate risks.

We found that an increase in farmers' official credit bank access resulted in an increase in the likelihood of choosing a change in water exchange schedules and reduced the probability of choosing water treatment. Thus, credit improved low-income farmers' chances of affording extra farm costs (e.g., water pumping, chemical/antibiotics) to increase the frequency of water exchange when climate risks appear. However, farmers who fail to borrow from banks may access other credit sources, such as loans from family members or other stakeholders (input agents/processing shrimp companies). For instance, farmers who access loans given by input agents often have to commit to purchasing these agents' shrimp inputs (e.g., seed, feed, chemicals) or have to establish pond structures or irrigation systems following guidance from seed companies. Hence, these forms of credit availability often come with strings attached that require choices that may not be optimal in isolation.

4.5 Farmer Perception of climate risks

Muralidhar et al. (2012) illustrated how high temperatures and irregular weather affect shrimp pond water quality via changes in salinity, pH, and oxygen levels, leading to higher disease occurrence, slower shrimp growth, and high development of algal blooms. Our study found that farmers' perceptions of irregular weather and drought significantly positively impacted farmers' behavior in choosing measures related to water treatment. Irregular weather also increased changes in feed schedules/stocking density. These two adaptation approaches seem to work appropriately as shrimp farmers put more effort into balancing water quality in grow-out ponds during irregular weather. In contrast, farmers who perceived the impacts of drought were less likely to choose early harvesting. Drought is a clear CR for shrimp aquaculture, but it is also an integral part of farmers' operations, as Mekong shrimp farmers must deal with drought in some form or another every year. In practice, early harvesting seems to be adopted to mitigate the loss when warnings of coming crises occur, for instance, notification of disease outbreaks following cross pollution in neighboring farms or forecasted natural disasters (e.g., heavy storms, typhoons). Mekong farmers may implement a partial harvest or harvest the entire crop in such cases, depending upon the situation.

5. Conclusion and Policy Implications

This study explores the key determinants of shrimp farmers' adaptive measures to cope with climate risks using the MNL model on farm-level survey data. Results display the vital role of farmers' perceptions regarding irregular weather and drought in motivating the selection of adaptation. Other primary factors shown to influence farmer adaptation choices to climate risks are socio-economic factors (experience, education); farm characteristics (farm size, pond numbers); knowledge sharing (training attendance), and service accessibility (extension services, credit access). Contributing to the literature on shrimp aquaculture and policy implications, we provide quantitative evidence of the explanatory variables that positively encouraged farmers' responses regarding adaptive measure selection.

This study has limited the adaptations to five major choices made by shrimp farmers for coping with climate risks. Our results indicate that most measures shrimp farmers take in response to climate risks are related to balancing the quality of water (e.g., changing the water exchange schedules, water treatment, and conservation), like Galappaththi et al. (2020)'s suggestions. Our study identified that change in water exchange schedules was the most preferred adaptation when farmers perceived climate risks. The results reveal substantial differences in the choice of adaptive measures across production systems. These findings may provide input to policymakers about which adaptive measures could be encouraged for intensive versus extensive farms, involving water conservation for the former and changing water exchange schedules for the latter. In addition, the provincial government may encourage water conservation by supporting the shrimp farmers' education attainment and increasing their access to extension services. Local government can boost the application of adjusted feeding schedules/stocking density and/or water treatment by providing alert messages regarding the severity of climate occurrences (e.g., irregular weather and drought) to increase awareness of the CR impact level. The target is to improve the coping capacity related to a change in water exchange schedules in extensive farming. In that case, the government may put more funding and effort into training programs and increase the accessibility of bank credit to farmers. Our findings highlight that intensive farms apply all adaptive measures barring change in water exchange schedules, more than extensive farms. Quach et al. (2017) suggest that policymakers should encourage more intensive shrimp farming to increase the resilience of shrimp farmers concerning climate change and its effects. In our analysis, we cannot make this link explicitly; intensive farms chose various adaptive measures regarding water quality when they perceived climate risks, while extensive farmers focus on one measure, namely change in water exchange schedules. It should be noted that Shelton (2014) finds that improved extensive shrimp farming is more sustainable for small-scale farmers, both environmentally and economically, despite it providing lower profitability than intensive shrimp farms. Therefore, from our results, the government can further motivate extensive farmers to carry out their favored adaptation choice by encouraging knowledge sharing (training program attendance) and increasing service accessibility (credit access).

As mentioned, high-tech intensive farming, also known as super-intensive shrimp farming, is increasingly desired in Vietnam to bolster further production. Super-intensive farming requires technological improvements such as bio-floc waste-water treatment and closed systems for assuring biosecurity and water quality, resulting in less pollution and lower impact of irregular weather. This system allows increased stocking density and more crops per year. However, super-intensive farming requires investment in capital, knowledge, and improved technology. In our survey, we have yet to include super-intensive farms. Though this may be the trend in the future, such investment is still a challenge for low-income shrimp farmers in less developed countries. Extensive and intensive/semi-intensive farming may be expected to continue in parallel with super-intensification. Furthermore, different market niches based on preferences for small-scale, sustainable products may allow for the coexistence of different types of farming in the future.

Finally, assessing how efficient and successful each adaptation measure is, while interesting and relevant, nevertheless lies beyond the scope of this paper and is left for future research.

Author contributions

The first author develops the survey and data collection, organizes, analyzes, and interprets the data, and develops the paper. The second author contributes to data analysis and interpretation and development the paper. Both authors have reviewed the final document and agree with its contents.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A:

Table A1 Literature reviews on farmer choices in argi-aquaculture industries

Authors	Country	Method used	Data	Findings/ key factors affecting the farmer. adaptation choices	Adaptive measures
Do & Ho. (2022)	Vietnam	Endogenous swtiching regression	374 shrimp farmers	Education of farmers (+), Farmers' belief on changes in climatic conditions (+)	Upgrading pond dikes, Lining ponds with plastic sheets Having settling ponds
Ali et al. (2021)	Pakistan	BLR	400 smallholder farmers	Household size (+), assets (+), distance from the market (-), market access (-), food aid (-), food price (+) floods (-), disease (-), district dummy (-)	Tree planting Early sowing Terracing Irrigation Water Harvesting Non-farm activities Crop diversification
Thompson et al. (2021)	Nigeria	MNL	480 fish farmers	Experience (+), Income (+), access to credit (+), pond size (+)	Use of concrete/plastic pond Flood control/provision of the water outlet Provision of alternative water supply
Aftab et al. (2021)	Pakistan	MVP	500 households	Wealth (+), off-farm work (-), market distance (-), no. of tribes (+), agriculture extension (+), farming experience (+/-), farm to reiver distance (-). flood duration (+/-), past adaption (+)	Plinth elevation Communal flood preparation Shelterbelt Grain storage
Khan et al. (2021)	Pakistan	MVP, ordered probit model	480 rice growers	Farmer's age (+), Farm size (+), farm ownership (+/-), tube well (+/-), canal irrigated land (+), livestock holding (+/-), active farm labor (+/-), active farm labor (+), off-farm income (+/-), farm advisory (+/-), credit services (+/-), climate information access (+/-)	Supplementary irrigation Irrigation time changes Climate-smart variety Cultivation dates changes Fertilizer management Farm resizes. Short duration rice
Oparinde (2021)	Nigeria	MNL, Multinomial Endogenous Switching Regression	288 fish farmers	Gender (+), membership of cooperative (+), level of education (+), experience (+/-), non-farm income (+), no. of pond (+), awareness (+), perceived temperature (+), perceived rainfall (+)	Bore-hole construction. Stocking time adjustment Embankment creation

Wang et al. (2021)	China	BLR Multiple logistic regression	539 households	Informal social network (-), formal social network (+), interpersonal trust (+), institutional trust (+), social norms (+), no. of household labors (-), education level (-), income (-), no. of livestock (+), farmland (+), location condition (-), policy accessibility (+), perception of temperature change (-), perception of precipitation change (-)	Expansion strategy Adjust strategy. Contraction strategy
Khong et al. (2020)	Vietnam	Censored generalized, Poisson regress, Negative Binomial regression. Ordered logit model	441 rice farmers	Farmers are aware of the causes and impacts of salinity intrusion and have adopted autonomous strategies to cope. Drivers of preferences for long-term public adaptation strategy (sea dikes construction): farmers' willingness to pay for construction (+), impact on farm housing value (-), impact on water supply for agricultural activities (+), impact on habitation environment (+), impact on regional economics (-)	22 effectiveness of salinity adaptation strategies adopted by farmers (such as: constructing the dykes, changing planting time, etc.) 24 intended future salinity adaptation strategies (migrating to other places, getting information from TV, radio, etc.)
Kamba (2020)	Nigeria	MNL	150 arable crop farmers	Experiences (-), education (+), household size (-), years of residence (+), extension contact frequency (+), credit access (+)	Good soil conservation techniques Irrigation/Drainage/ Wetland farming Targeting rains to plant Multiple strategies
Esfandiari et al. (2020)	Iran	MNL	360 rice famers	Cultivated land area (+), Seed (+), Fertilizer (+), Pesticide (+), Water (+), Age (-), Education (+), Family income (+), land size (-),	Adjusting crop sowing and harvesting day Modifying crop varieties Changing the area of land under cultivation Irrigation control mechanism Mix cropping
Singh (2020)	India	Multi-criteria analysis (BLR)	200 agriculture farmers	Rainfall (+), temperature (+), Education (+), Land size (+), Income (+/-), above poverty line (+/-), Irrigated area (-), Agriculture credit (+/-), Information of climate (+), crop insurance (+/-),	Cropping pattern change Switch to non-farm Improve irrigation. Early maturing varieties Less water requiring crops
Joffre et al. (2019)	Vietnam	Hierarchical regression Mediation analysis	251 shrimp farmers	Water quality management: stocking density WLS (+), stocking density P. monodon (+), public/ private sector interactions (+), susceptibility climate (-), severity of market risk (+)	Water quality management Feed input practices Disease control input practices

				Feed input practices: stocking density WLS (+), public/ private sector interactions (+), neighbor interactions (-), susceptibility climate (-), severity of market risk (+) Disease control input practices: stocking density WLS (+), cluster (+), public sector interactions (+)	
Usman et al. (2019)	Malawi	BLR MVP	220 fishers	Age (-), education level (+), access to land (-), fishing experience (+), household size (+), fishing income (-), total income (-), social capital (+), access to extension service (+)	Increasing fishing effort Migration of fishing effort Investing in improved gear Livelihood diversification
Moroda et al. (2018)	Ethiopia	MNL	397 agricultural households	Gender (+/-), farmland size (+/), total annual income (+/-), access to weather forecast (+/-), access to credit service (+/-), distance to input/output market (+/-)	Crop management-related strategy Land management-related strategy Diversification into non-farm activities
Thoai et al. (2018)	Vietnam	BLR MVP	400 farmers (agri-forestry)	Farm size (+), Farming experience (+), Damage level (+), Access to credit (+), Attendance to training (+), Farm size (+)	Change crop variety. Switch to new cultivar types. Adjust farming calendar. Follow-up weather forecasts Intercropping
Arunrat et al.(2017)	Thailand	MNL	661 rice farmers	Gender (+), experience (+), Schooling (+), household size (+), farmer income (+), land ownership (+), credit access (+), distance to input/output markets (-), training attendance (+), communicating adaptation to climate change (+)	Changing rice varieties Practicing crop rotation Changing from old production site to another site Increased use of water sources and irrigation system Farming calendar adjustment
Abidoye et al. (2017)	South-East Asian*	MVP	1615 smallholder farmers	Perceived more drought (+/-), perceived more flood (-), household size(+/-), perceived more pets(+), education (-), experience (+/-), use past (+/-), expert time use past (+/-), Perceived warning (+), perceived more pets (+), primary job (-),	Crop date Crop variety Irrigation Crop type
Dubey et al. (2017)	Indian Sundarbans delta	Descriptive statistics, qualitative information	451 fish farming	73% of surveyed farmers were affected by cyclonic events. The common coping measure against cyclonic was to repair of pond dyke through earthwork (37%)	Repair pond dyke Increase pond dyke height. Plantations on pond dyke Pumping of saline water Application of lime Addition of fresh water Application of fertilizer

					Application of cow dung
Addisu et al. (2016)	Ethiopia	Heckman probit MNL	300 household	Hecman probit: Sex (-), education (-), wealth status (-), distance to the nearest health center (+), extension (-) MNL: Agro-ecology (+/-), Education (+), transport to market (-), income from crop sale (+)	Use of climate change resilient variety (both crop and livestock) Crop diversification Change planting date. Irrigation Other measures
Seekao & Pharino (2016)	Thailand	Descriptive analysis Social vulnerability index Descriptive analysis	100 shrimp farmers experienced flood vulnerability	Main adaptive practices: Placing nets around shrimp ponds (12.6%), constructing dykes (28.1%) Early harvesting prior to a flood occurring (9.7%)	Placing nets around shrimp ponds Increasing the height of dikes Early harvesting prior Changing the calendar for culturing shrimp.
Ahmed & Diana (2015)	Bangladesh	Field survey	100 shrimp farmers (Penaeus monodon)	Adaptation and management strategies to climate change for shrimp culture: Community-based adaptation and integrated coastal zone management	Community-based adaptation (6 adaptation strategies such as the construction of dams, and development of water irrigation) Integrated coastal zone management (6 adaptation strategies such as mangrove plantation and conservation, etc.)
Alam (2015)	Bangladesh	MNL	546 rice farmers	Education (+), tenure status (-), experience (+), electricity (+), Moderate institutional access (+), climate awareness – adversely affected (+), slightly affected (-)	Increased use of surface water Crop diversification Land use change
Shameem et al. (2015)	Bangladesh	Descriptive analysis	30 shrimp farmers	Main adaptive practices: 47% of the sample adopted the measure of increased embankment height.	Increased embankment height Digging pond inside the fish farm Liming Use medicine. Placing net around shrimp field
Alauddin & Sarker (2014)	Bangladesh	BLR MNL	1800 rice farmers	perceived severe drought (+/-), severe groundwater depletion (+/-), farm size (+), livestock ownership (+),	Direct-seeded rice More irrigation water. Supplementary irrigation

				access to climate information (-), access to subsidy (+), access to electricity for irrigation (-)	Short-duration and drought-tolerant rice varieties Changing planting dates and others Water-savings non-rice and horticultural crops
Gebrehiwot & Van Der Veen (2013)	Ethiopia	MNL	400 rural households	Sex (+), age (+), Education (+), Farm size (+), Farm income (+), information on climate change (+), temperature (+), precipitation (+/-), Argo-ecology (+)	Crop diversification Soil conservation Application of irrigation Planting trees Change in planting date.
Sarker et al. (2013)	Bangladesh	BLR MNL	550 rice farmers	Gender (+), age (+), education of household heads (+), experience (-), household assets, annual farm income (+), farm size (+), tenure status (+), farmer-to-farmer extension (+), access to credit (+), access to subsidy (-), access to electricity (+),	More irrigation Growing short-duration rice Greater emphasis on supplementary irrigation Changing planting trees Agro-forestry Use of different crop varieties Non-rice crops
Sofoluwe et al. (2011)	Nigeria	MNL	100 crop farmers	Off-farm (+), livestock (-), access loan (+)	Soil conservation Planting trees Planting variety Early and late planting
Gbetibouo et al. (2010)	South Africa	MNL	794 households	Household size (-), Experience (+), wealth (+), highly fertile soil (+), extension (+), farm size (+), credit (+), tenure (+) Latitude (+/-, longitude (+/-), temperature (+)	Portfolio diversification Irrigation Changed planting dates. Changed amount of land Livestock feed supplements Other
Abery et al.(2009)	Vietnam	Participatory approach	Stakeholders	Climate changes: hot weather, too much rain, canal/river level rise, storm, irregular seasonal change Impacts ranked: water quality, disease, slow growth, dike management, tidal flood leads to shrimp escape, sluice gate damage,	List of solutions/ adaptive measures with responsible agents and timing among farmers, scientists, and government.
Deressa et al. (2009)	Ethiopia	MNL	1000 households	Gender (+), education (+), age (+), income (+/-), non-farm income (+), extension (+), information on climate change (+), farmer – to- farmer extension (+), credit	Soil conservation Crop varieties Planting trees

	availability (+), local agroecology (+), temperature (+), precipitation (-)	Changing planting date Irrigation

Notes: BLR: Binary logistic regression, MVP: Multivariate probit regression, MNL: Multinomial logit model.
* including Bangladesh, Indonesia, Sri Lanka, Thailand, and Vietnam
Shelton, (2014) suggested the list of potential adaptation measures in fisheries and aquaculture from several countries (Bangladesh, Nepal, Vietnam, China, Fiji, Palau, Peru, Mexico, Egypt, Guinea, Senegal, Benin, Kenya, United Republic of Tanzania, Mozambique, Lake Malawi, and mitigating the different climate change impacts (reduced yields, increased variability, reduced profitability, increased risk, and increased vulnerability for those living near rivers and coasts)

Appendix B: The correlation matrix among choice options

	Change in feeding schedule/stocking practices	Change in water exchange schedule	Water treatment	Water conservation	Early harvesting
Change in feeding schedule/stocking practices	1				
Change in water exchange schedule	-0.2608	1			
Water treatment	-0.1505	-0.2896	1		
Water conservation	-0.2223	-0.4279	-0.2469	1	
Early harvesting	-0.1461	-0.2811	-0.1622	-0.2397	1

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