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Climate change adaptation actions by fish farmers: evidence from the Niger Delta Region of Nigeria*

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This paper examined climate change adaptation strategies in fish farming and the effect of such methods on the profit of fish farmers in the Niger Delta region of Nigeria, Africa's most populous country. Using cross-sectional data obtained from 420 fish farmers from the region and applying multivariate probit and instrumental variable regressions, the study found that fish farmers have adopted a broad range of strategies to address climate risk and that these have significantly increased farmers' profit. Our findings indicated important relationships between certain farm, socio-economic and institutional characteristics and the adaptation actions. The study provides useful insight into factors that potentially encourage the adoption of livelihood-enhancing climate risk adaptation strategies by fish farmers in the Niger Delta region and similar contexts.

Key words: adaptation, fish farming, instrumental variable regression, multivariate probit model, profit.

1. Introduction

Fish farming and aquaculture are important livelihood activities in Africa (AUC-NEPAD 2014; Roscher *et al.* 2018). However, they have been identified as

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significant contributors to climate change yielding around seven per cent of global agricultural greenhouse gas emissions (He *et al.,* 2018). On the other hand, fish farming is also significantly affected by climate change. Increased temperature, shift in rainfall regime, changes in weather pattern, the deterioration of water quality and extreme climate events such as flood and drought are all having an impact (Oyebola *et al.* 2018; Kim *et al.* 2019). Stress, delayed fish breeding, reduced fish production, reduced feeding and growth, deterioration of pond water quality and fish mortality are some negative impacts resulting from these climate change events (IPCC 2007; Brander 2010; Pimolrat *et al.* 2013).

In Africa, fish farmers are especially susceptible to the vagaries of climate that can result in decreased production and negative profit (Oyebola and Fada 2017; Oyebola *et al.* 2018). For fish farmers to maximise profit and meet the continent's rapidly growing demand for fish, they must use adaptation to manage the risks posed by climate change. The concept of adaptation is useful for understanding how fish farmers can respond to actual or anticipated climate risks, while also maintaining and developing capacities that will enable them to exploit new opportunities (IPCC 2007).

Nigeria is Africa's most populous country and ranks second in production of farmed fish in the continent (Oyebola *et al.* 2018). The country faces varying degrees of climate risk of which rising temperature, changing rainfall pattern, distribution and volume, and extreme climate events have been reported as the principal shocks (BNRCC 2011). These risks affect the production of farmed fish in the country and also threaten the objective of meeting the daily protein requirements of Africa's largest nation. Therefore, understanding the adaptation decisions of fish farmers in Nigeria and their effectiveness is very important if Africa is to feed her growing population.

While the literature on climate change adaptation and fish farming is emerging (Nigerian Environmental Study Action Team 2011; Arimi 2014; Isife and Ekeremor 2015; Onada and Ogunola 2016; Oyebola *et al.* 2018), research on the impact of chosen adaptation methods on fish farm profits is largely nonexistent in Africa. Consequently, this study attempts to fill this gap with evidence from the Niger Delta region of Africa's most populous country, Nigeria. We investigated both the determinants of climate risk adaptation among fish farmers in the Niger Delta region of Nigeria and the effect of such adaptation strategies on farmer's profit. More specifically, we explored what determines farmers' choices of climate risk management strategies and then proceeded to examine the effectiveness of chosen adaptation strategies on fish farm profits. It is common knowledge that farmers combine different/multiple strategies to manage climate change impacts. Therefore, rather than focusing on one strategy as other studies have done (See Nigerian Environmental Study Action Team 2011; Arimi 2014), we explored the determinants of simultaneous adoption of multiple adaptation strategies by fish farmers. This better reflects the reality faced by farmers. As far as the authors are aware, this is the first study that includes an analysis of this kind for Africa more generally and for Nigeria in particular.

This paper makes a further contribution to the climate change adaptation literature by exploring the potential joint nature of the decision to adopt multiple strategies in addressing climate risk. By using a multivariate probit model (MVP), we explored the interdependencies across the different adaptation strategies adopted by fish farmers who all share the objective of maximising production. The study also used the instrumental variable regression (IVR) approach to consistently estimate the effect of climate risk adaptation on farmer profits. The findings provide insight into factors that encourage the adoption of different kinds of climate risk adaptation strategies in fish farming in the Niger Delta and similar contexts. The findings further indicate that fish farming is profitable and that adaptation actions can significantly increase the profit of this business. These results can therefore be applied in the development of policies, programs and plans to support the adoption of livelihood-enhancing climate risk strategies in the Niger Delta region of Nigeria and similar contexts.

2. Study area

The geographic coordinates of the study area – the Niger Delta – are between latitudes 4°15′N and 6°30′N and longitudes 4°30′E and 8°30′E (Onojeghuo and Blackburn 2011). The region is home to the nine oil-producing states of Nigeria: Abia; Akwa-Ibom; Bayelsa; Cross River; Delta; Edo; Imo; Ondo; and Rivers (Figure 1). It is the largest wetland in Africa with an area of over 70,000 square kilometres (Bariweni *et al*. 2012). It has a significant population of fish farmers and widespread poverty (National Bureau of Statistics 2005). Water covers about 2,370 square kilometres, while stagnant swamps cover approximately 8,600 kilometres (Etiosa and Ogbeibu 2007), making the area vulnerable to climate risks such as floods, sea level rise and erosion. The last population census conducted in Nigeria put the population of the area at 31,224,577 persons (National Bureau of Statistics 2006). Fish farming across states in the Niger Delta is similar in terms of the systems used by farmers and the size of the business, as documented by Iruo (2014). Iruo (2014) reported that fish farming in the Niger Delta is dominated by small-scale operators practising semi-intensive management systems and sourcing their fish feed and fingerlings from accredited suppliers and hatcheries, respectively.

3. Methodology

3.1 Data and sampling

This paper used data from a cross-sectional survey conducted from October 2017 to April 2018 in seven states in the Niger Delta region of Nigeria. The study applied a purposive sampling technique to select states from the region. It considered the severity of the impact of floods in the region over the past

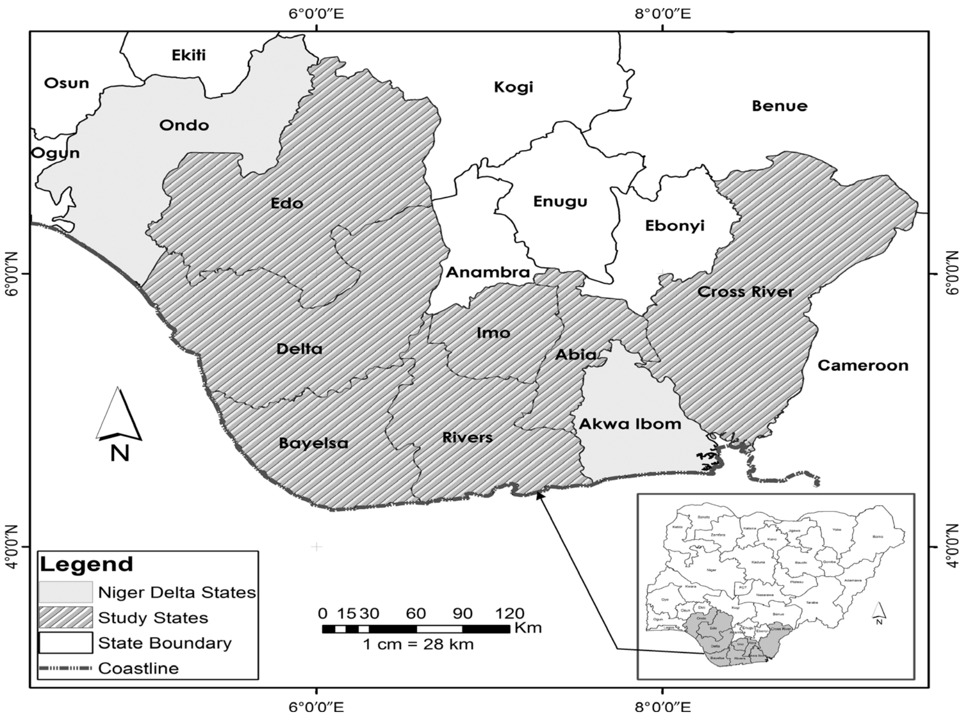

Figure 1 Map of Niger Delta region.

5 years (2012–2017), since flood is a major threat to fish farming (Oyebola *et al*. 2018). This five-year period was characterised by flood of varying degrees, with the 2012 flood described as the worst because it severely affected 32 of the 36 states of Nigeria. So significant was the 2012 flood that the government of Nigeria considered it a national disaster. All nine Niger Delta states were affected by the flood, though the reported impact differed significantly across states (Obeta 2014). States affected were divided into four categories, A to D, in decreasing order of the severity of the reported impact (Obeta 2014). Bayelsa and Delta states fell into Category A; Cross River, Edo and Imo states fell into Category B; Abia, Ondo and Rivers states fell into Category C, while Akwa Ibom state fell into Category D (Adebayo and Oruonye 2012; Obeta 2014). We selected all states in Categories A, B and C (except Ondo state) because these states frequently experienced floods in the period since 2012. Furthermore, the magnitude of the impacts, losses and damages of the 2012 flood in Akwa Ibom and Ondo states were substantially less than in the other states of the Niger Delta region (Adebayo and Oruonye 2012; Food and Agriculture Organization 2012; Federal Government of Nigeria 2013; Eri and Fogden 2013). The study focused on those states that had suffered more severe impacts, losses and damages to fish farming assets. The selected states were Delta, Cross River, Abia, Imo, Edo, Rivers and

Bayelsa. Local government areas (LGAs) within each selected state were classified according to the concentration of fish farmers (high concentration and low concentration), using the subjective opinions of officials working in Agricultural Development Programs in the region. This was similar to the method of Wang *et al.* (2018), where the subjective opinions of officials working in the Agricultural Bureau in China were used to categorise townships in Chinese counties based on the quality of their agricultural production infrastructure. Six LGAs were randomly selected from each state from the high concentration category. We employed the same approach in selecting five communities from each selected LGA. We sampled 42 LGAs and 210 communities. Finally, two fish farmers were selected in each sampled community, making the sample size of the study 420 fish farmers ($7 \times 6 \times 5 \times 2$).

A semi-structured climate change adaptation questionnaire was developed to help obtain data from the farmers. It focused particularly on their socio-economic and institutional characteristics, their farm and asset characteristics, their perception of climate change, their fish farming adaptation strategies, and the costs and revenue of production of farmed fish. Farmers were first asked if they were aware of climate change and the direction of that change as perceived over the past twenty years. They were asked to indicate the various climate change shocks/events that they have experienced. For climate shocks experienced, they were asked to state the measures adopted in managing them. We allowed the adaptation strategies to emerge from the farmers' own descriptions, rather than imposing our ideas and definitions as part of the questions we asked them. The adaptation strategies defined by the farmers themselves were then subjected to content analysis and, in all, nine strategies were identified.

The fish farmers included in the study were also asked to indicate the variable inputs used in their fish farming, including the quantity used and the cost of each input. They were then asked to indicate the fixed inputs used in fish production in their farms, including the quantity, costs and lifespan of each input. Cost was reported in Naira while lifespan was reported in years. The farmers were then asked to indicate the quantity of their output, the unit price of the output and the number of production cycles in each year, with quantity reported in kilograms and output price reported in Naira. We successfully conducted and completed 420 face-to-face interviews, where the content of the questionnaire was read and interpreted to all the farmers interviewed. The interviewers recorded the responses of these 420 farmers.

3.2 Data analysis

Net return (NR) analysis, MVP and IVR were adopted for data analysis. The NR was calculated using the formula stated in equation 1:

$$\text{NR} = \text{TR} - (\text{TVC} + \text{TFC}) \quad (1)$$

where NR = net return; TR = total revenue; TVC = total variable cost; TFC = total fixed cost. Depreciation on fixed cost items was calculated using the straight line method.

3.2.1 Econometric specification

Econometric models including ordinary least-square regression, binary logit, binary probit and multinomial logit models have dominated analysis of the factors influencing climate change adaptation actions adopted by farmers in Nigeria (See Onwuemele and Olorunfemi 2010; Apata 2011; Nigerian Environmental Study Action Team 2011; Uzokwe 2012; Otitoju 2013; Arimi 2014; Obayelu *et al*. 2014; Chukwuone 2015; Olutegbe and Fadairo 2016; Oriakhi *et al*. 2017; Onyeneke *et al*. 2018). Applying these models has deepened our understanding of the drivers of climate change adaptation. However, by treating adaptation strategies singly and failing to account for the interdependencies of farmers' adaptation actions, these models can seriously limit our understanding. Farmers usually have many adaptation strategies available to them and are likely to combine multiple strategies to manage climate risks. Therefore, empirical models need to account for the likely simultaneous or sequential adaptation decisions that farmers make. It is important to use an econometric tool which models the effects of predictors on various adaptation strategies taken simultaneously. It is also important to ensure that the disturbance terms of each adaptation strategy are freely correlated (Mulwa *et al*. 2017). The study therefore used MVP, which models the simultaneity/interdependencies of multiple adaptation decisions, thus overcoming the shortcomings in previous studies in Nigeria.

This study has nine climate change adaptation strategies as endogenous variables,

$Y_1, \ldots, Y_9$ such that:

$$Y_i = 1 \text{ if } \beta X + \varepsilon > 0 \quad (2)$$

and

$$Y_i = 0 \text{ if } \beta X + \varepsilon \leq 0 \; i = 1, 2, \ldots, 9 \quad (3)$$

where $i = 1,2,\ldots,9$ are the adopted climate risk adaptation actions.
X is a vector of the exogenous variables; β, parameter estimates of the exogenous variables; and ε, random error vectors distributed as a multivariate normal distribution with zero mean, unitary variance and an $n \times n$ correlation matrix (Mulwa *et al*. 2017).

Endogenous variables. We asked farmers about their perceptions of climate change, the climate events they have experienced and the strategies used in addressing the risks they have encountered. From the responses gathered, nine broad climate risk management strategies in fish farming were identified. These were seeking early warning information about climate risks; siting ponds far from flood-prone areas; stocking hardy fish species; insurance; fish diversification; livelihood diversification; sinking a borehole in the farm to ensure a regular water supply; planting economic trees around fish pond areas; and consistent monitoring of pond water. These constitute the endogenous variables in this study and are further expressed as:

Y_1 = seeking early warning information about climate risks (yes = 1, no = 0); Y_2 = siting ponds far from flood-prone areas (yes = 1, no = 0); Y_3 = improved/hardy fish species/breeds (yes = 1, no = 0); Y_4 = insurance (yes = 1, no = 0); Y_5 = fish diversification (yes = 1, no = 0); Y_6 = livelihood diversification (yes = 1, no = 0); Y_7 = sinking a borehole in the farm for regular water supply (yes = 1, no = 0); Y_8 = planting economic trees around fish pond (yes = 1, no = 0); Y_9 = consistent monitoring of pond water (yes = 1, no = 0).

Exogenous variables. The choice of predictors was informed by empirical review and data availability. The following variables were considered exogenous to climate change adaptation in fish farming:

X_1 = education (years spent in school); X_2 = age (years); X_3 = household size (number of persons); X_4 = income (Naira); X_5 = gender (male = 1, female = 0); X_6 = contact with extension agents (count/year); X_7 = fish farming experience (years); X_8 = marital status (married = 1, not married = 0); X_9 = credit (Naira); X_{10} = pond size (m^2); X_{11} = time taken to walk to the market (minutes); X_{12} = membership of farmer groups (yes = 1, no = 0); X_{13} = ownership of television (yes = 1, no = 0); X_{14} = participation in workshop and training (number attended last year); X_{15} = climate event experienced (dummy = 1 if the farmer had experienced flood/heat waves, 0 otherwise); X_{16} = reliance on government support (yes = 1, no = 0).

We present the justification of the choice of the exogenous variables as follows. Evidence from many sources indicates that educational attainment enhances the adoption of technologies and climate change adaptation (Czaja *et al*. 2006; Maddison 2006; Franken *et al*. 2012; Franken *et al*. 2014; Lee *et al*. 2015) because educated farmers are more experimental and innovative and are better equipped to adopt the technologies and strategies needed to manage climate risks. There is no consensus in the literature on the relationship between age and climate change adaptation because the impact is location and technology/strategy-specific (Gbetibouo 2009; Deressa *et al*., 2008; Shiferaw and Holden 1998; Kebede *et al*. 1990). Hence, age affects climate change adaptation decisions of farmers negatively and positively. Household size is expected to influence farmers' adaptation decisions positively because as a proxy for farm labour, it reduces the constraints on adopting labour-intensive adaptation practices (Mignouna *et al.* 2011a; Mignouna *et al.* 2011b; Ndamani and Watanabe 2016). Regarding gender, studies show that male farmers adapt more readily to climate change than their female counterparts because men have more agricultural resource endowments (Deressa *et al.*, 2008; Doss and Morris 2001; He *et al.* 2019) and women's access to agricultural resources and information is often slim due to traditional barriers (Ndiritu *et al.* 2014). Scholars have reported both positive and negative impacts of marital status on adoption in Nigeria (Adesope *et al.* 2012; Elemasho *et al.* 2017). We anticipate that marital status will have a positive influence on climate change adaptation decisions because married farmers generally tend to be more responsible and committed to the farm business than their single counterparts.

Income aids adaptation because most climate risk response strategies come in the form of farm inputs and richer farmers are more likely to adopt these than their poorer counterparts (Shiferaw and Holden 1998). Higher income farmers are usually less risk averse than their lower income counterparts (Velandia *et al.* 2009; Deressa *et al.*, 2008). Hence, income is theorised to affect climate risk response strategy positively. The impact of credit on climate change adaptation in the literature is generally reported to be positive (Simtowe and Zeller 2006; Gbetibouo 2009; Mulwa *et al.* 2017). Given that credit places farmers in a position to meet any additional costs arising from adaptation (Onyeneke *et al.* 2018), it aids climate risk management. We therefore hypothesised that credit is positively related to climate risk response strategy.

Agricultural extension improves technology adoption and climate change adaptation among farmers, because it provides information about the adoption of innovations and improved farm management practices (Mulwa *et al.* 2017; Onyeneke *et al.* 2018). We therefore hypothesised that extension is likely to affect adaptation positively. Membership of social groups is expected to positively influence adaptation to climate change. Social organisations offer members the platform to network and share ideas. Members of such groups also share important agricultural production management information, as well as information about training and workshop opportunities. These in their turn allow farmers and other stakeholders to exchange ideas about ways to increase yields and build resilience to climate risks (Munasib and Jordan 2011; Uddin *et al.* 2014; Ndamani and Watanabe 2016). Ownership of a television set enhances technology adoption and adaptation to climate change because what viewers learn from television programs may help them adapt better to climate change than their counterparts who do not have access to television. Participation in relevant training and workshops is important in building farmers' capacity to adapt to climate change. It is therefore expected to positively influence the adaptation of fish farmers to climate change (Arimi 2014; Trinh *et al.* 2018a). Farmers who stand to receive government support in the event of climate shock are more likely to adapt to climate change than their counterparts without such support (Arimi 2014).

Also, Xu and Findlay (2019) found that government support enhances adaptation particularly for constrained farmers. Therefore, this variable is expected to have a positive effect on climate change adaptation.

Farming experience is expected to have a positive impact on adoption of climate-resilient strategies because the more experienced farmers have better knowledge of farm management and understand the practices and technologies needed to improve production and enhance climate resilience (Onyeneke *et al*. 2012; Temesgen *et al*. 2014). Pond size, which represents the size of the farm business, has received considerable attention in the climate change adaptation literature and is commonly considered to have a positive impact on adaptation (Onyeneke *et al*. 2012; Tarfa *et al*. 2019). Adoption of technologies tends to take place earlier and more rapidly on larger farms than on smaller farms. This is because adoption of innovations requires an important investment which larger farms are more ready to take on. Time taken to access the market decreases farmers' uptake of climate-resilient practices and technologies because adaptation requires inputs, which are usually bought in markets (Hassan and Nhemachena 2008; Deressa *et al*. 2011). Therefore, the longer it takes a farmer to get to the market where adaptation inputs are sold, the less likely he/she is to adapt to climate change. An earlier experience of a significant climate event influences adaptation to climate change (Spence *et al.,* 2011; Mulwa *et al*. 2017). Adaptation is a learning process and having experienced any climate event therefore puts a farmer in a better position to learn, be prepared and ensure that he/she does not suffer the risks/shocks associated with such event whenever it reoccurs. This variable is expected to increase uptake of adaptation strategies.

3.2.2 Effects of adaptation strategies on fish farmers' profit

Farmers usually adopt a mix of adaptation strategies in response to climate change, and these strategies are often interdependent (Mulwa *et al*. 2017). The adoption of multiple adaptation strategies in climate risk management is a decision often made as a result of farmers' observable and unobservable characteristics (Di Falco *et al*. 2011). The objective of most farmers is to maximise output and profit. This suggests that the decision to combine multiple adaptation strategies is made to maximise profit. This is why farmers tend to use a mix of adaptive practices that will yield maximum unobserved utility for them (Barberies 2013).

We therefore adopted IVR to determine the impact of climate change adaptation strategies on the net return of fish farmers. The climate change adaptation strategies chosen are considered to be endogenous to the dependent variable – net return. Farmers' socio-economic, institutional and farm characteristics are the control variables which affect both net return and adaptation decisions. There may be unobservable factors other than the control variables that affect both net return and adaptation. This makes it difficult to interpret differences in the net return in terms of the impact of adoption of climate change adaptation strategies. Addressing this endogeneity problem requires an appropriate econometric technique such as the IVR.

Finding a suitable instrument is one of the major challenges of this technique. A suitable instrument must be correlated with the endogenous variable (in this case, adaptation), but not directly related to the outcome variable (in this case, net return) (Chege *et al*. 2015). Gbetibouo observed that adaptation to climate change involves two stages – perception and adaptation. Farmers will first perceive climate change before choosing a response strategy (Gbetibouo 2009). We therefore chose perception of climate change as the instrument because perception cannot affect net return except through the channel of adaptation.

The questionnaire included questions on farmers' long-term perception of changes in temperature, rainfall volume and variability. The perception about each climate change stressor was categorised into 'decreased', 'unchanged' and 'increased', and farmers were asked to tick the category perceived for each stressor. The authors constructed a variable called 'perception index' to represent the instrument. This variable was calculated by adding the number of correctly perceived climate change stressors by each farmer. For example, if a farmer correctly perceived the direction of change in temperature, rainfall volume and variability when compared to the established trends of climatic stressors in the literature and the records of the Nigerian Meteorological Agency, the farmer would score 3 as his/her perception index.

The basic criteria for choice of IVR technique were as follows: relevance criterion, implying that the instrument must be a significant predictor of the endogenous variable (adaptation); and exclusion restriction, signifying that the instrument is uncorrelated with outcome variable (net returns). First-stage results of the IVR in Table 5 confirmed the first criterion. We carried out a simple linear regression between net return and perception index and found no relationship between the outcome and instrument. This confirmed the second criterion. The number of adaptation options chosen was the endogenous variable in the IVR. The choice of the count of adaptation strategies was informed by the interrelationships/interdependencies between individual adaptation strategies in the pairwise correlation results of the MVP in the result section. Since the farmers employed multiple adaptation strategies to manage climate risks, it is logical to use the sum of an individual's adaptation choices as the endogenous variable in the IVR. The IVR model of the study is stated as follows:

$$Y_i = \beta_1 A_i + \beta_2 X_i + \varepsilon_1 \quad (4)$$

$$A_i = P_i \delta_1 + \delta_2 X_i + \varepsilon_2 \quad (5)$$

where Y_i = outcome/dependent variable (net return measured in Naira) of the ith farmer; A_i = number of adaptation strategies of the ith farmer with parameter estimate, β_1; X_i = vector of household level control variables of the ith farmer with parameter vectors, β_2; P_i = perception index/instrument with parameter estimate, δ_1; ε_1 and ε_2 = error terms with zero means and nonzero correlations.

4. Results and discussion

4.1 Adaptation strategies

The climate risk response measures adopted by farmers in the Niger Delta are presented in Table 1. The table shows that the most common adaptation practice was consistent monitoring and changing of pond water, with majority (90.71 per cent) of farmers adopting this strategy. Variations in water quality parameters can affect the physical, physiological and biological performances of fish, thus inducing stress (Boyd 1979). With rising temperature and an associated decrease in dissolved oxygen in pond water, followed by frequent flood and the acidification of rainwater in the Niger Delta, the quality of pond water is deteriorating. This induces stress, reduces feeding and leads to mortality of farmed fish. Many fish farmers will naturally respond by consistently monitoring and changing pond water. This could be the reason why almost all the fish farmers opted for this strategy as a way to manage climate risks. Fish farmers in the region monitor pond water by observing fish for signs of lethargy (gasping for air at the surface of water, abnormal swimming patterns and reduced physical activities) and respond by changing pond water. Another common strategy was siting fish ponds far from flood-prone areas. Approximately 85.50 per cent of the farmers adopted this strategy. Flood represents a major threat to fish farming in Nigeria and other developing countries (Ahmed *et al*. 2014; Oyebola *et al*. 2018). When floods occur, ponds receive run-off water which usually overflows built barriers and sweeps fish away, leaving behind debris that is harmful to the remaining fish (Jackson 2014). This commonly occurs in the Niger Delta and fish farmers now find that siting fish ponds far from flood-prone areas and

Table 1 Climate change adaptation strategies of fish farmers

S/N	Adaptation strategy	Frequency	Percentage
1	Seeking early warning information about climate risks	234	55.71
2	Siting ponds far from flood-prone areas	359	85.48
3	Improved fish breeds	306	72.86
4	Insurance	21	5.00
5	Fish diversification	129	30.71
6	Livelihood diversification	341	81.91
7	Sinking boreholes for regular water supply	256	60.95
8	Planting shallow-rooted trees	196	46.67
9	Consistently monitoring and changing pond water	381	90.71

building strong protective barriers against floods are effective measures to manage flood-related climate risks.

Livelihood diversification is another important adaptation effort of fish farmers in the Niger Delta. About 82 per cent of the fish farmers adopted this option as a climate risk management measure. Pursuing a single form of livelihood puts fish farmers at great risk when a shock occurs and, to overcome this, many fish farmers in Nigeria combine fish farming with other livelihood activities including petty trading, crop and poultry farming and artisan works. Fish farmers in the area also responded by integrating fish farming with other aquaculture activities such as fish processing, fish gear production and cultivation of aquatic vegetables. Diversifying into other means of livelihoods is an important strategy for building resilience and managing climate risks (Food and Agriculture Organization 2014).

Many farmers (72.86 per cent) adopted the strategy of introducing improved fish breeds/hardy fish species. During the course of data collection, many fish farmers stated that they liked rearing the African catfish because of its high resistance to poor water quality conditions and disease and its tolerance to climate change. Isife and Ekeremor (2015) found that the culturing of improved fish species (hybrids) such as the African catfish was the strategy most adopted by fish farmers in Bayelsa state to manage climate risks. The study also found that sinking boreholes and seeking early warning information about climate risks were adaptations adopted by more than 50 per cent of fish farmers. As mentioned above, flood, increasing temperature and changing rainfall patterns in Nigeria cause the destruction of fish farm assets and inputs, as well as the deterioration of pond water quality (Adebayo and Oruonye 2012; Food and Agriculture Organization 2012; Ipinjolu *et al.* 2013; Federal Government of Nigeria 2013; Eri and Fogden 2013; Adeleke and Omoboyeje 2016). Fish farmers in the area responded to these risks and impacts by seeking information on climate change and consistently monitoring and changing pond water. It was observed during data collection that fish farmers who sought early warning information about climate risks and who have boreholes sunk near their ponds monitored and changed pond water when necessary. Insurance was adopted by 5 per cent of the farmers to manage climate risks in fish farming. Nigerian farmers do not yet appreciate the protection that insurance provides. A study by Isife and Ekeremor (2015) in Bayelsa state found that aquaculture insurance was the climate change adaptation measure least used by fish farmers.

4.2 Determinants of climate change adaptation decisions made by fish farmers

4.2.1 Interdependencies among the adaptation strategies

The analysis of the determinants of climate change adaptation decisions made by fish farmers, using sixteen predictors, was done using a MVP. The appropriateness or nonappropriateness of the choice of MVP was tested using the likelihood ratio test. The result of likelihood ratio test (χ^2 = 224.88,

Table 2 Determinants of climate change adaptation in fish farming

Variables	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9
X_1	−0.002 (−0.30)	0.001* (1.69)	0.002 (0.48)	0.003* (1.74)	0.009* (1.66)	0.007* (1.88)	0.014** (2.40)	0.010 (1.53)	0.001 (0.30)
X_2	−0.002 (−0.59)	−0.001 (−1.38)	−0.003 (−1.00)	−0.001 (−0.60)	0.010*** (2.90)	0.001 (0.22)	−0.011*** (−2.78)	0.007 (1.54)	0.001 (0.93)
X_3	−0.037*** (−2.71)	−0.003* (−1.82)	−0.015 (−1.33)	−0.004 (−0.99)	−0.033** (−2.43)	0.025*** (2.95)	0.017 (1.19)	0.072*** (4.74)	−0.002 (−0.59)
X_4	4.73e-08 (0.45)	−9.27e-09 (−0.79)	8.08e-08** (2.08)	1.50e-08** (2.44)	1.42e-07*** (2.68)	1.35e-07 (0.70)	1.41e-07* (1.81)	8.45e-08 (0.45)	1.11e-07 (1.12)
X_5	0.211*** (3.42)	0.006 (0.72)	0.090* (1.81)	−0.002 (−0.12)	0.126** (2.33)	−0.025 (−0.63)	0.194*** (3.24)	−0.170*** (−2.69)	0.007 (0.32)
X_6	0.138*** (4.78)	0.017*** (3.60)	0.096*** (3.51)	0.009 (1.39)	0.034* (1.71)	0.066*** (2.96)	0.040* (1.66)	0.073*** (2.98)	0.005* (1.73)
X_7	0.006 (1.06)	0.010*** (6.74)	0.003 (0.63)	−0.002 (−0.77)	−0.0001 (−0.02)	0.001 (0.41)	0.016*** (3.09)	−0.030*** (−5.39)	0.005** (2.05)
X_8	−0.074 (−0.79)	−0.015 (−0.95)	0.005 (0.06)	−0.002 (−0.07)	−0.009 (−0.12)	−0.022 (−0.33)	0.034 (0.37)	0.145 (1.55)	0.026 (0.64)
X_9	−6.00e-07 (−1.25)	3.61e-08 (0.50)	1.36e-07** (2.32)	9.51e-08 (0.91)	1.06e-06*** (2.62)	4.60e-07* (1.75)	8.81e-07* (1.74)	4.84e-07 (0.97)	6.88e-07 (1.35)
X_{10}	0.010** (2.07)	0.001 (1.15)	−0.01 (−1.37)	0.0001*** (3.58)	0.002** (2.31)	−0.010** (−2.36)	0.040*** (3.66)	0.020** (2.51)	0.002** (2.16)
X_{11}	0.003 (1.52)	0.0003 (1.48)	−0.003 (−1.90)*	−0.0001 (−0.29)	−0.005*** (−2.88)	−0.002** (−1.99)	0.008*** (−4.46)	0.0001 (0.06)	−0.00003 (−0.06)
X_{12}	−0.052 (−0.89)	−0.005 (−0.71)	0.036 (0.74)	−0.021 (−1.25)	0.079* (1.66)	0.067* (1.67)	0.086 (1.49)	−0.002 (−0.03)	−0.021 (−1.15)
X_{13}	0.237*** (3.99)	0.007 (0.89)	0.100** (2.02)	0.016 (0.97)	−0.09 (−1.63)	0.015 (0.39)	−0.032 (−0.54)	−0.062 (−0.96)	0.012 (0.57)
X_{14}	0.003** (2.22)	0.0001** (2.07)	0.012** (2.03)	0.004* (1.69)	0.019 (1.47)	0.002 (0.18)	0.011 (0.72)	−0.021 (−1.26)	−0.002 (−0.31)

Table 2 (*Continued*)

Variables	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9
X_{15}	0.137** (2.39)	0.007** (2.15)	−0.042 (−0.96)	0.039** (2.22)	0.091* (1.95)	0.037 (1.01)	−0.117** (−2.20)	0.299*** (4.81)	0.029 (1.33)
X_{16}	0.169* (1.72)	0.013* (1.81)	−0.317*** (−3.24)	0.012** (2.47)	0.002 (0.02)	0.014 (0.23)	0.058 (0.58)	−0.415*** (−4.14)	−0.203*** (3.54)
Likelihood ratio Chi square	224.88***								

Note: Values in parentheses are *z*-values.
***Significance at 1% level.
**Significance at 5% level.
*Significance at 10% level.

$P < 0.01$) was statistically significant, showing dependence of the error terms of the different adaptation equations (Table 2). This implies that the use of MVP to model determinants of climate change adaptation decisions made by fish farmers was appropriate.

The study also probed further to determine whether farmers' adaptation decisions were complementary or substitutes as shown in Table 3. The table shows that 26 of the 36 pair correlations among the adaptation strategies were positive while ten were negative. This indicates that many of the adaptation practices were complementary while relatively few were substitutes. The correlation coefficients were statistically significant and positive in 19 paired adaptation strategies while four pairs were statistically

Table 3 Pairwise correlation coefficients of the adaptation strategies

Adaptation decision	Pairwise correlation coefficient
$RhoY_1Y_2$	0.136***
$RhoY_1Y_3$	0.116**
$RhoY_1Y_4$	0.161***
$RhoY_1Y_5$	0.057
$RhoY_1Y_6$	0.147***
$RhoY_1Y_7$	−0.016
$RhoY_1Y_8$	−0.021
$RhoY_1Y_9$	0.138***
$RhoY_2Y_3$	0.052
$RhoY_2Y_4$	0.020
$RhoY_2Y_5$	0.201***
$RhoY_2Y_6$	0.044
$RhoY_2Y_7$	0.183***
$RhoY_2Y_8$	−0.183***
$RhoY_2Y_9$	0.015
$RhoY_3Y_4$	−0.057
$RhoY_3Y_5$	−0.104**
$RhoY_3Y_6$	0.213***
$RhoY_3Y_7$	0.236***
$RhoY_3Y_8$	0.152***
$RhoY_3Y_9$	−0.011
$RhoY_4Y_5$	0.034
$RhoY_4Y_6$	0.082*
$RhoY_4Y_7$	−0.040
$RhoY_4Y_8$	0.087*
$RhoY_4Y_9$	−0.190***
$RhoY_5Y_6$	0.070
$RhoY_5Y_7$	−0.038
$RhoY_5Y_8$	0.101**
$RhoY_5Y_9$	0.177***
$RhoY_6Y_7$	0.089*
$RhoY_6Y_8$	0.096**
$RhoY_6Y_9$	0.140***
$RhoY_7Y_8$	−0.161***
$RhoY_7Y_9$	0.215***
$RhoY_8Y_9$	0.103**

Note: ***, ** and * indicate statistical significance at 1%, 5% and 10% levels, respectively.

significant and negative. The study found that seeking early warning information was significant and complementary with siting fish ponds far from flood-prone areas, culturing improved fish species, insurance, livelihood diversification and consistent monitoring and changing of pond water. Early warning information is very important to fish farmers, allowing them to adjust their management practices and aids in managing the impacts of anticipated climate risk. When early warning information is available to fish farmers, they tend to monitor pond water regularly, site ponds far from flood-prone areas, buy insurance cover for their farms, culture fish species that can tolerate anticipated climate risks, and pursue other livelihood activities as a means of increasing income and building resilience. Siting fish ponds far from flood-prone areas exhibited a significant complementary relationship with fish diversification, and sinking boreholes for regular water supply, but exhibited a significant substitute relationship with planting shallow-rooted economic trees. The study also observed significant and complementary use of improved fish breeds, livelihood diversification, sinking boreholes and planting shallow-rooted trees, while there was a significant negative relationship between adoption of improved fish breeds and culturing diverse fish species. The possible reason for the negative relationship between adopting improved fish breeds and culturing diverse species could be due to the fact that the two practices perform similar roles in climate risk management and are generally close substitutes. Buying insurance was complementary with livelihood diversification and tree planting, but indicated a substitute relationship with consistent monitoring of pond water. The study found a positive correlation between livelihood diversification and sinking boreholes, planting trees and consistent monitoring of pond water. Planting shallow-rooted economic trees on farms is an important livelihood activity because the more market-oriented farmers sold some of the fruits and other products of such trees to raise their income (Somarriba *et al.* 2017). Sinking boreholes on farms could promote other livelihood activities for fish farmers such as cassava and fish processing, which require a constant water supply. Farmers who sunk boreholes on their farms combined it with monitoring pond water while farmers who planted trees tended to monitor and change pond water when necessary. Trees on farms may fertilise or pollute pond water if not checked regularly and this may be the reason farmers tended to check and monitor pond water regularly. There was a substitute and significant relationship between sinking boreholes and planting trees. The results shown in Table 1 indicate that the sampled fish farmers combined different adaptation strategies in managing climate risks. Recent results from climate change adaptation studies confirmed that farmers usually adopt a mix of strategies in managing climate risks (Boansi *et al.* 2017; Trinh *et al.* 2018a).

4.2.2 Determinants of choice of adaptation decisions

The results relating to determinants of farmers' choice of adaptation strategies are presented in Table 2. Educational attainment of farmers significantly increased the likelihood of siting ponds far from flood-prone areas, insurance, fish and livelihood diversification, and sinking boreholes for regular supply of water to ponds. The adoption of insurance, fish and livelihood diversification, as well as sinking boreholes, increased by 0.3, 0.9, 0.7 and 1.4 per cent, respectively, for every one-year increase in farmer's level of education. Farmers with a higher level of education understood and appreciated the importance of insurance more than the less educated farmers. Livelihood and fish diversification are important risk management measures which the more educated practised more because of their knowledge and skills. In Nigeria, farmers with a higher level of education are usually engaged in different livelihood activities with the objective of diversifying their income and managing the impact of shock on any of their activities. Sinking boreholes is capital-intensive in Nigeria and the more educated farmers had better access to capital than the less educated ones and by extension were more likely to have boreholes sunk on their farms. Higher educational attainment therefore enhances fish farmers' adoption of climate risk management measures. This corroborates the findings of Onyeneke *et al.* (2018) on determinants of climate-smart agriculture in south-east Nigeria.

Farmers' age significantly affected fish diversification and sinking of boreholes. Older fish farmers were less likely to sink boreholes, but more likely to adapt using fish diversification. A one-year increase in fish farmers' age is associated with a 1.0 per cent increase in adoption of fish diversification and a 1.1 per cent reduction in sinking boreholes. High uptake of fish diversification as an adaptive strategy among older farmers could be associated with their accumulated knowledge about the importance of stocking different fish species to manage risks. Relatively, low use of boreholes by older farmers could be associated with their lesser understanding of the importance of boreholes on farms. During data collection, the authors observed that many older farmers felt that having boreholes would increase the cost of the business.

Household size had a significant effect on seeking early warning information about climate risks, siting fish ponds far from flood-prone areas, fish diversification, livelihood diversification and tree planting. Household size decreased uptake of early warning information about climate risks, siting fish ponds far from flood-prone areas and fish diversification, but enhanced uptake of livelihood diversification and tree planting. In Nigeria and many parts of Africa, active and productive household members usually engage in various livelihood activities to raise income for family upkeep. A unit increase in fish farmers' household size would yield a 2.5 per cent increase in the adoption level of livelihood diversification and reduce the uptake of early warning information, siting fish ponds far from flood-prone areas and fish diversification by 3.7, 0.3 and 3.3 per cent, respectively.

Farmers' income and access to credit significantly increased the adoption of improved fish species, insurance, fish diversification, livelihood diversification and sinking boreholes. These adaptation strategies require sufficient financial well-being for adoption, which explains why farmers with higher incomes and better access to credit adopted these strategies more than their poorer counterparts with less access to credit. This corroborates the finding of Arimi (2014) on determinants of climate change adaptation strategies used by fish farmers in Lagos state, Nigeria.

Gender significantly influenced uptake of early warning information, improved fish species, fish diversification, sinking boreholes and tree planting. Being a male fish farmer significantly increased the uptake of early warning information by 21.1 per cent, sinking boreholes by 19.4 per cent, improved fish species by 9.0 per cent and fish diversification by 12.6 per cent. However, it reduced the planting of shallow-rooted trees and crops around fish ponds by 17.0 per cent. Unlike their female counterparts, male fish farmers are not constrained by traditional/cultural barriers and this puts them at an advantage over female farmers in seeking information from various sources to improve their farm activities. They also have better access to farming inputs such as fingerlings and labour than their female counterparts; this enhances their ability and capacity to adopt improved and different fish species. Diverging from *a priori* expectation, female fish farmers adapted more readily to climate change through planting shallow-rooted trees and vegetables around fish ponds more than their male counterparts. The possible explanation of this result could be linked to womens' greater involvement in agriculture in Nigeria, which may spur them on to cultivate other crops such as vegetables, banana and plantain around ponds as another means of increasing food for household consumption. As with the findings discussed above, other researchers have reported diverse relationships between gender and climate change adaptive strategies (Wondimagegn and Lemma 2016; Saguye 2016; Onyeneke *et al*. 2018; Trinh *et al*. 2018a).

Agricultural extension significantly increased the uptake of all the adaptation strategies except insurance. An additional contact with agricultural extension workers significantly increased seeking early warning information by 13.8 per cent, siting fish ponds far from flood-prone areas by 1.7 per cent, improved fish species by 9.6 per cent, livelihood diversification by 6.6 per cent, fish diversification 3.4 per cent, tree planting by 7.3 per cent, sinking boreholes by 4.0 per cent and consistent monitoring of pond water by 0.5 per cent. Agricultural extension provides information on improved fish farming techniques and technologies and could also serve as an important source of information on climate change. Farmers who have more access to extension are in a better position to access climate risk management information and improved agricultural technologies and techniques. This is in line with the findings of Ofuoku *et al*. (2008) and Onyeneke (2017) on the drivers of adoption of agricultural technologies in Nigeria.

Farming experience significantly encouraged siting ponds far from flood-prone areas, sinking boreholes and consistent pond water monitoring, but discouraged planting trees near fish farms. A unit increase in farming experience would increase siting ponds far from flood-prone areas by 1.0 per cent, sinking boreholes by 1.6 per cent and consistent pond water monitoring by 0.5 per cent. Highly experienced fish farmers usually have more information about adaptation practices suitable for climate risks and are more knowledgeable about fish farming management techniques than those who are less experienced. Experience negatively affected planting trees around ponds. Trees harbour pests/predators and more experienced farmers believe that having trees around ponds increases the incidence of pest attacks. However, less experienced farmers preferred having trees near ponds to serve as shade/protection against rising temperature, to cool the ponds and increase dissolved oxygen in the water. Similarly, Manus and Singas (2014) reported that farming experience is significantly related to the adoption of fish farming technologies.

Pond size significantly increased adaptation through the uptake of early warning information, insurance, fish diversification, sinking boreholes, planting trees on the farm and consistent pond water monitoring. Pond size determines the size of the fish farm business and large-scale fish farmers were more inclined to buy insurance to indemnify their farms in case of any shocks, seek early warning information about climate risks, sink boreholes (which is

Table 4 Profit analysis of 100 m^2 fish pond

Item	Unit	Unit price (N)	Quantity	Value (N)
Revenue				
Fish	kg	1,000	1219	1,219,000
Total returns (A)	NA	NA	NA	1,219,000
Variable costs				
Wage on labour	Month	30,000	4	120,000
Feed	Bag	6,500	100	650,000
Fingerlings	Number	40	1200	48,000
Supplement/medication	Sachet	700	4	2,800
Fertilisers/chemicals	Bag	1,500	2	3,000
Transport	NA	NA	NA	5,800
Electricity	kWh	30.93	121.3	3,752
Other costs	NA	NA	NA	10,080
Total variable cost (B)	NA	NA	NA	843,432
Gross margin (A-B)	NA	NA	NA	375,568
Fixed costs				
Depreciation on borehole and tank	NA	NA	NA	20,833
Depreciation on pond	NA	NA	NA	37,000
Depreciation on other assets	NA	NA	NA	1,561
Total fixed cost (C)	NA	NA	NA	59,394
Total cost (B + C)	NA	NA	NA	902,826
Net returns	NA	NA	NA	316,174

NA, not applicable.

Table 5 Effect of adaptation decisions on profit of fish farming

Variable	Adaptation equation	Net return equation
Adaptation	NA	99,607.10*** (2.95)
Perception	0.243** (2.55)	NA
Education	0.040*** (2.92)	2,400.12 (0.88)
Age	0.002 (0.24)	−758.91 (−0.63)
Household size	−0.087*** (−2.61)	−2,289.56 (−0.43)
Income	5.26e-07* (1.82)	0.40** (1.96)
Gender	−0.057 (−0.40)	5,782.09 (0.31)
Extension contact	0.335*** (5.77)	30,756.32** (2.48)
Farming experience	0.026** (2.05)	−190.61 (−0.10)
Marital status	−0.055 (−0.27)	−12,046.90 (−0.46)
Credit	2.36e-06** (2.18)	0.21** (2.24)
Pond size	0.020* (1.67)	70.53*** (2.82)
Walking distance to the market	−0.008** (−2.02)	−1,131.55* (−1.87)
Cooperative membership	0.120 (0.87)	9,192.07 (0.49)
Television ownership	0.328** (2.29)	25,800.30 (1.09)
Training/workshop attended	0.017** (2.49)	2,629.60** (2.38)
Climate event experienced	0.181* (1.67)	121,036.50*** (6.07)
Reliance on government support	−0.481** (−1.97)	−73,563.01* (−1.83)
Number of observations	420	420

Note: NA, not applicable.
Values in parentheses are *t*-values.
***Significance at 1% level.
**Significance at 5% level.
*Significance at 10% level.

expected to make monitoring and changing pond water easier) and stock different fish species that adapt to the vagaries of weather. However, pond size had a negative impact on livelihood diversification. Fish farmers with large farms were less inclined to pursue other livelihood activities as that might take away the time needed in their main investment. Arimi (2014) found that stock size reduced adoption of climate change adaptation strategies by fish famers in Lagos state, Nigeria.

Distance to the market and membership of cooperative societies emerged as significant predictors of fish farmers' choice of adaptation strategies. For example, distance to the market significantly decreased adoption of improved fish species, fish diversification, livelihood diversification and sinking boreholes. This variable determines farmers' access to fish farming inputs including improved and diverse fish species and the materials needed to sink boreholes. Therefore, the farther the distance to the market, the less likely it is that fish farmers will be able to access the inputs needed for climate risk management and fish farming. Kiprono and Matsumoto (2014) and Ulimwengu *et al.* (2009) maintained that transportation costs make it more difficult for farmers to purchase inputs and sell their farm products too. Similarly, membership of cooperative societies increased adoption of livelihood diversification and culturing diverse fish species. Membership of groups increased the adoption of livelihood diversification by 6.7 per cent and fish diversification by 7.9 per cent. Members of cooperatives share information about improved fish farming technologies and climate risk management. They also pool resources, which makes it easy for members to acquire capital to diversify their income sources and buy different fish species for culturing. Farmers in cooperative societies also share innovative ideas, challenges and successes with one another and collaborate in decision-making (Uddin *et al.* 2014). Boansi *et al.* (2017) and Menike and Keeragala-Arachchi (2016) found that membership of groups of this kind enhances adoption of climate risk management measures.

Attending training courses and workshops on climate change and fish farming enhanced uptake of early warning information about climate risks, siting fish ponds far from flood-prone areas, improved fish species and insurance. Through these training courses and workshops, farmers gain a better understanding of the impact of climate change and the strategies that are likely to minimise impact. This is in line with the findings of Arimi (2014) in Nigeria, where training courses increased adaptation of fish farmers to climate change. Also, Trinh *et al.* (2018b) noted attendance at training courses as a significant predictor of climate change adaptation in agricultural production in Vietnam. Ownership of television encouraged uptake of early warning information about climate risks by 23.7 per cent and improved fish species by 10.0 per cent. Having a television on which it is possible to watch weather forecasts and programs on improved fish farming technologies and techniques makes farmers more prepared to respond to climate change.

Having experienced any untoward climate event significantly increased seeking early warning information about climate risks by 13.7 per cent, fish diversification by 9.1 per cent, insurance by 3.9 per cent, siting ponds far from flood-prone areas by 0.7 per cent and planting trees around the farm by 29.9 per cent. Adaptation is a learning process and farmers who have experienced climate events in the past learn how to respond by choosing these adaptation strategies and becoming more resilient. Another significant predictor of fish farmers' adaptation to climate change is reliance on the government for support. This significantly increased seeking early warning information about climate risks, siting ponds far from flood-prone areas and insurance. However, the study recorded negative relationships between reliance on the government for support and consistent pond water monitoring, on-farm tree planting and adoption of improved fish species. Farmers who did not rely on the government for any support were more likely to adopt these strategies than their counterparts. Mulwa *et al.* (2017) similarly recorded both significant positive and negative impacts of reliance on the government for support and farmers' adoption of climate change adaptive strategies.

4.3 Profitability of fish farming

Results of the profitability of fish farming are presented in Table 4. Entries in Table 4 indicate that the total cost of fish production in a 100 m^2 pond was N902,826 with total variable cost of N843,432 and total fixed cost of

N59,394.20. The total variable cost contributed 93.42 per cent of total cost while fixed cost contributed 6.58 per cent. The net return was N316,174, implying that fish farming is profitable in the area. Iruo *et al*. (2019) also found that intensive and semi-intensive fish farming are profitable in the region.

4.4 Impact of adaptation decisions on profitability of fish farming

The impact of multiple adaptation actions on the profit of fish farmers was examined using IVR and is presented in Table 5. The first column shows the effects of the control variables and the instrument (perception) on adaptation while the second column shows the effects of the endogenous variable (adaptation) and control variables on farmer's profit. Generally, the signs of the coefficients of control variables, instrument and endogenous variable are *a priori* correct.

Income, extension services, access to credit, attending training courses and having prior experience of a climate event significantly increased farmer profit, while walking a considerable distance to the market and reliance on the government for support significantly reduced fish farmers' profit in the Niger Delta. The result implies that reliance on the government for support and poor market access exert penalties on profit of fish farms.

The instrument (perception) had a significant positive impact on adaptation. The authors also found that perception had no effect on fish farmers' net return, demonstrated in a simple regression carried out in the course of choosing the instrument. These are *a priori* correct and justify the choice of perception as the instrument of this study. Perception significantly influenced adaptation ($P < 0.05$) and correctly perceiving climate change is a precondition for the choice and degree of adaptation actions (Gbetibouo 2009). The impact of the number of climatic stressors correctly perceived on adaptation actions was 24.5 per cent, emphasising the importance of farmers' understanding of climate change and local knowledge in climate risk management in Africa.

The study found that adaptation significantly increased profit of fish farming in the area at 1 per cent level of probability. Fish farmers combined several adaptation strategies in climate change management and the impact of farmers' multiple adaptation actions on the profit of fish farming, as shown in Table 5, was as high as N99,607.10. Income, extension services, access to credit, attending training courses and having prior experience of a climate event significantly increased farmers' profit, while walking a considerable distance to the market and reliance on the government for support significantly reduced profit of fish farming in the Niger Delta. This result is consistent with the findings of Di Falco *et al*. (2011), Di Falco *et al*. (2012), Yegbemey *et al*. (2014), Peck (2017) and Kabir *et al*. (2017). Di Falco *et al*. (2011) and Di Falco *et al*. (2012) found that farmers' adaptation actions significantly increased food productivity, farm productivity and farm net revenues in Ethiopia. Yegbemey *et al*. (2014) found that climate change adaptation increased maize farmers' profit in Benin Republic. In Asia, Kabir *et al*. (2017) noted the effect of adaptation on farmers' profit in Western Bangladesh. Similarly, the contribution of adaptation to the profit of flood-resistant rice farmers in Laos has been reported by Peck (2017).

5. Conclusion

This study examined the determinants of decisions to undertake simultaneous climate adaptation actions, and the impact of such strategies on the profit of fish farmers. The study used cross-sectional data gathered from fish farmers in seven states of the Niger Delta region of Nigeria and employs MVP to analyse the simultaneous adaptation decisions of the farmers. It also used IVR to model the effect of adaptation decision on fish farm profit.

We found that fish farmers applied a broad range of strategies to address climate risk including seeking early warning information, siting ponds far from flood-prone areas, culturing improved fish species, consistent monitoring of pond water and livelihood diversification. These strategies were largely interdependent and exhibited some level of complementarity and substitutability. Farmers' socio-economic, institutional and contextual characteristics, including the characteristics of farms, determined the adoption of the strategies. The paper demonstrates the importance of simultaneous adaptation decisions in climate risk management in fish farming in Nigeria and similar contexts.

The study found that adaptation to climate change increased fish farm profit and fish farmers who correctly perceived climate change were likely to take up adaptation measures. Furthermore, income, extension, credit, training and experiencing climate events led to increased fish farm profit, while remoteness and reliance on the government for support decreased the profit. These findings show that it is necessary to design policies and interventions for climate change adaptation management in fish farming. Supporting formal and informal credit institutions to make loans available and accessible to fish farmers will help them adapt to climate change and will increase their profit and income. The importance of agricultural extension in the adoption of adaptive strategies underlines the need to provide more extension services to fish farmers. It will also be necessary to construct and rehabilitate rural roads with a view to improving fish farmers' access to the market. In addition, policy considerations that provide early warning information about climate risks, ensure improved fish species are readily available and accessible, and build fish farmers' capacity through training and workshops will increase farmers' resilience and improve the profit of this business.

The findings of this study are also important in developing aquaculture adaptation policies and plans in developing countries. As stated earlier, investing in adaptation enhances fish farming profit. In order to achieve increased farm profit, climate resilience and food security, government and other stakeholders in developing countries should prioritise investments in the adaptation of fish farming to climate change.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Questionnaire used for the survey