DLSU Business & Economics Review 24.2 (2015), pp. 32-44

Biophysical Vulnerability Impact Assessment of Climate Change on Aquaculture Sector Development in Sarawak, Malaysia

Rosita Hamdan
University of Malaysia Sarawak, Sarawak, Malaysia
University of Malaya, Kuala Lumpur, Malaysia
rositahamdan@gmail.com

Fatimah Kari
University of Malaya, Kuala Lumpur, Malaysia
fatimahkari@gmail.com

Azmah Othman
University of Malaya, Kuala Lumpur, Malaysia
othman.azmah47@gmail.com

This study is an assessment of the impact of climate change on the biophysical vulnerability of aquaculture production in Sarawak. The relationship between change in risk factors with the total aquaculture production and farmer's income is identified. It utilizes data from the survey done on 249 aquaculture farmers in Sarawak, as well as secondary data gathered from various government reports. The multiple linear regressions results verify that the mean minimum temperature has a positive significant effect on freshwater ponds, while relative humidity has a negative significant effect on brackish water ponds. The total aquaculture area has a positive significant effect on brackish water ponds and cages. The results are further supported by the bivariate Spearman's rho correlation results, which show that the increasing number of climate change events will decrease the aquaculture production and income of aquaculture farmers. It is found that water quality disturbance is the main biophysical vulnerability aspect of the aquaculture sector in Sarawak due to the impact of climate change. The impact of climate change through biophysical changes affects the water quality and poses a considerable challenge to small aquaculture farmers in Sarawak. Various adaptation strategies are urgently needed to mitigate the possible outcome of climate change risks in future.

JEL Classifications: Q22, Q51, Q54

Keywords: Climate change in risks, impacts assessment, aquaculture production, aquaculture income.

INTRODUCTION

The aquaculture sector has expanded and become an important contributor to the growth of the fisheries sector around the world. This sector is a strategic industry with a significant role in increasing the national food production, as well as fulfilling the domestic demand for fish. It not only provides an important source of animal protein for human consumption but also caters for the export demand of fish products. Aquaculture production helps to overcome decreasing fish stock due to over exploitation of fishing activities in coastal areas. In addition, aquaculture production also contributes to stabilizing the fisheries price in the market. The World Bank (2013) revealed that in the last three decades, aquaculture production increased from 5 million to 63 million tons, and captured fish from 69 million to 93 million tons. The volume of captured fish and aquaculture production contribute about 16.6% of animal protein supply and 6.5% of all protein for human consumption. Aquaculture activities have improved the quality of life and the livelihoods of low- and middle-income fishermen and farmers, as it ensures and improves food security and supply. In addition, it contributes to the development of infrastructure, diversifies and provides employment opportunities to fishermen and the nearby community, increases the income of fish farmers, and reduces poverty (Edwards, 2000).

The development of the aquaculture sector in Malaysia has shown a positive rapid growth in production over the years. The total volume of aquaculture production increased from 133,062 tons in 1998 to 500,000 tons in 2010 (Ministry of Finance, 1998; Ministry of Finance, 2010). This sector has increasingly provided employment, especially among the youth, where, in 2013, 41,822 workers were involved in the pond and cage system, an increase of 22,769 workers from the number recorded in 2004 (Department of Fisheries, 2004; Department of Fisheries, 2013). Since 2003, many programmes have been introduced by the government to enhance the potential of this sub-sector. Huge funds were invested and allocated to improve facilities, especially in the aquaculture industrial zones (AIZ) area. These efforts have been made with the goals of increasing aquaculture contribution towards the national food production, solving the insufficient supply of captured fish and reducing the exploitation of marine fish.

Biophysical Vulnerability of Climate Change in Aquaculture

The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) defined biophysical vulnerability as a function of hazard, exposure, and sensitivity. The term biophysical refers to the physical components with hazards and their first order physical impacts on the affected system that acts to reduce the damage from impact. Brooks (2003) defined the biophysical vulnerability as a function of the regularity and rigorousness of hazards that cause harm in which this interaction is known as the outcome risks, while Blaikie, Cannon, Davis, and Wisner (1994) highlighted the measure of hazards or exposure in the system that interacts with social vulnerability. In the context of the fishery community, vulnerability is a function of risk in which people may be exposed; the sensitivity of their livelihood system to those risks and their ability to adapt, cope with, or recover from the impact of an external shock (climate change) to their livelihood system (Allison & Horemans, 2006).

There are arguments concerning the connection of biophysical and socio-economic vulnerability. Some researchers believed that biophysical vulnerability exist due to the socio-economic vulnerability; others believed that biophysical and socio-economic vulnerability were independent factors and social vulnerability was a factor of biophysical vulnerability (Brooks, 2003). Moreover, there are two streams of biophysical vulnerability study in the context of aquaculture. The first concentrated mainly on pure science research, such as the study done by Barange and Perry (2009), while the second stream focused on biophysical vulnerability combine with the socio-economic impact (Daw, Adger, Brown, & Badjeck, 2009). The biophysical vulnerability is categorized into two scales or spheres known as internal and external scales. The internal scale factors of biophysical vulnerability are topography, environmental situation, and land use, whereas, the external factors refer to events, such as severe storms, earthquakes, and sea level change. The level of sensitivity to climate change impact influenced by the internal biophysical is known as danger, while the external biophysical influence to the environmental circumstance is known as a hazards.

Vulnerability is an integral part of the causal chain of risk, and altering vulnerability is one effective risk-management strategy. Biophysical assessment explains the situation of environmental risk or physical environment change and how it harms the aquaculture production and producers welfare. The climate fluctuations affect the physical yield of aquaculture species and increase the farmer's production risk. However, Daw et al. (2009) gave a contradictory idea concerning biophysical vulnerability effects, whereby, in the long run, there is a positive result from the negative impact, that is, from the increase and recruitment of fisheries ecosystem resilience to the changes in the future. The sensitivity of the aquaculture sector can be measured by the number of farmers or fishers, poverty, proportion of aquaculture export value to fish export value, employment sector size, total production, and daily consumption of fish products (WorldFish, 2007). The physical impact of climate change differs from one place to another and the effect varies in respect of humans and the environment (World Bank, 2010).

There were several studies that attempted to discuss and identify the gap on the general theoretical and conceptual aspects of biophysical vulnerability of climate change on fishing communities such as in the case study of Fijian and Mekong Delta fisheries community (Daw et al., 2009). The current study is an additional attempt to add on to the existing literature by focusing on the biophysical vulnerability of climate change on the development of Sarawak's aquaculture sector. Nevertheless, the impact on local community is much more complicated to be captured given the variation in spatial and regional weather variation. With the exceptional of demographic factors, this study initially concentrates only on understanding the exposure, sensitivity, and effects of the biophysical factors that constitute the physical and ecological constraints to aquaculture production in Sarawak. The clear understanding on the relationship between the biophysical aspects of climate change on the aquaculture sector will also provide further evidence on the socioeconomic vulnerability among producers with limited resources.

Climate Change Challenges in Aquaculture Production

Currently, maintaining sustainable growth and the demand for aquaculture production are great challenges for fish farmers in many countries in the world including Malaysia. Besides the financial, technical, market, human, and stakeholder factors that influence aquaculture development in Malaysia (Idris, Mohamed Shaffril, D'Silva, & Man, 2013), environmental risks, such as climate change are among the crucial problems and major threats to the fisheries sector, as this sector is sensitive and directly affected by uneven or severely changing climatic patterns. Sustainable aquaculture growth is influenced by ecological factors known as abiotic factors and biotic factors. When biophysical factors change, it raises the problem of climate change risks in the aquaculture sector, as this modifies the normal pattern and circulation of ecology that fits fish growth (Tidwell et al., 1999).

Based on the Intergovernmental Panel on Climate Change (IPPC) Fourth Assessment Report 2007, climate change has heightened the risks to aquatic systems as it has had an uncertain effect on the acidification of oceanic water, coral bleaching, uneven distribution and timing of freshwater flows, and diminished coastal wetlands (IPCC, 2007). Ocean acidification, habitat damage, change in oceanography, disturbance to precipitation, and freshwater unavailability affects marine, freshwater fisheries, and aquaculture productivity as these occurrences might implicate high probabilities of disease outbreaks, which causes mass fish mortality (Daw et al., 2009; Mohanty, Mohanty, Sahoo, & Sharma, 2010). A rise in sea level, storm intensity and frequency, extreme weather events, or a wide range of human pressures affects fishing communities and the economic activities in the vicinity of the coastal and low lying zones (O'Brien, Sygna, & Haugen, 2004; De Silva & Soto, 2009). Moreover, alteration to the river surface and inland water temperature are among the major drivers of change that modify the physiological, ecological, and operational aspects of aquaculture activities and exacerbate the negative impact on the world aquaculture systems (De Siva & Soto, 2009; World Bank, 2010). Other climate change risks to the aquaculture sector includes factors such as humidity, sunlight intensity, oceanographic factors, and modification of hydrological processes, such as dissolved oxygen in water and pH change (De Silva & Soto, 2009), floods and precipitation, drought event, and water stress. These risks affect production in that the growth rate of fish is diminished and the fish become sluggish and extremely susceptible to disease threats resulting in a major cause of death to the fish (Hambal, Mohd. Akhir, & Saniah, 1994).

Another concern is that climate change events increase the costs of the aquaculture sector operation due to rising managerial costs, especially in fish feed and in getting quality fries, increased competition for good natural resources for aquaculture activities, and restructuring and fixing the damage to the aquaculture infrastructure. The climate change impacts on aquaculture production differ due to location (such as region), aquaculture practice system, space, time, size, and changeability (De Silva & Soto, 2009).

Impact of Climate Change on Aquaculture Production in Malaysia

As with other countries, Malaysia has also experienced the effects of climate change risks as weather variations have become increasingly volatile and severe. The climate variability and severe changes in weather patterns affect the rise in sea levels and rainfall, and increase the risk of flooding and droughts. Floods are one of the major threats of climate change to the aquaculture sector in Malaysia. In 2007, floods caused severe loss of production and income to aquaculture farmers in Muar and Segamat (Idris et al., 2013), and affected a few aquaculture areas in Sarawak in 2010. Since 1946, flood events have frequently had a disastrous and significant socio-economic impact on communities, particularly in the coastal area. These disastrous events not only affected the production and income but also the physical damage to the aquaculture cages and ponds in Kuching. The consequences of floods are low water quality and sediments flows (in river water and the high streams), which causes damage to the structure of the ponds and cages in inland and coastal aquaculture activities.

The changes in temperature and precipitation are usually followed by drought and flood seasons. Moreover, aquaculture species, especially shrimps, are profoundly affected by the water stratification as a result of changes in precipitation, temperature, and run-off in river water. The water stratification leads to the outbreak of diseases to the cultured fish and shrimps in all stages of the species growth, as has been experienced by the aquaculture sector in Malaysia (Hambal et al., 1994; Ministry of Finance, 2011). In addition, the alteration of nutrients in the seawater due to surface wind streams with higher CO_2 concentration levels, and uneven distribution of ocean currents causes ocean acidification. Such events led to the mass mortality and disease outbreaks in the cages in Sematan and Lawas, Sarawak. During the rainy seasons, farmers faced worse river pollution conditions due to the chemical and fertilizer effluent from nearby agriculture and palm oil plantations when rainwater flows into the rivers.

Drought seasons lead to the problem of water stress in aquaculture activities. Furthermore, deforestation activities and the clearance of mangrove forests for logging, agricultural, and other industrial activities escalate the water acidification problems and high sediment concentrations in the rivers. It has been reported that during the rainy season, water ran from the pervasive acid sulfate soils to the river and poison the cultured fish and prawns in Perak and Johor (Hambal et al., 1994) and caused unproductive growth of aquaculture species in Lawas and Limbang, Sarawak. Other impacts of climate change to the aquaculture production loss in Malaysia have been identified and recorded in several reports. These include water intrusion, water deterioration, and White Spot disease outbreaks to aquaculture species in Penang in 1992 (Hambal et al., 1994); problems of severe drought due to El Nino Southern Oscillation in Selangor, Sabah, and Sarawak in 1997, and also in all states of Malaysia in 2009; reports in local newspapers of floods and water stratification in Sungai Semerak, Kelantan, in 2007; and Streptococcus disease outbreaks in Peninsular Malaysia aquaculture production in 2010 (Ministry of Finance, 2011).

Although the significant impacts of climate change on the agriculture sub-sectors in Malaysia have been widely researched by past researchers, there has been a lack of focus on the relationship between the impact of climate change and socio-economics, and the adaptation in the fisheries and aquaculture sector (Daw et al., 2009). In contrast, the global impact of climate change risks to the national aquaculture sector have been widely discussed (Kelly & Adger, 1999) in Norway (Schjolden, 2004), Canada (Chu, Mandrak, & Minns, 2005), India (Mohanty et al., 2010) and the Philippines (Food and Agricultural Organization [FAO], 2011). Although concern about the environmental consequences on aquaculture production sustainability has risen, only a few studies focused on the biophysical vulnerability of climate change on the aquaculture sector in Malaysia. Therefore, this study attempts to explore the relationship between biophysical vulnerability with aquaculture production and farmers' livelihood. This study hopes to impart the findings and knowledge gathered from the aquaculture farmers to the government and related agencies to enable them to reduce the impact of climate change and develop relevant and robust strategies and solutions to enhance the competitiveness of Malaysia's aquaculture sector. Furthermore, this study is important, as it will help enhance potential adaptation information to climate change and identify the adaptive capacity of farmers in confronting hazards.

METHODOLOGY AND RESEARCH DESIGN

This study used primary and secondary data analysis in identifying the relationship between the biophysical factors and aquaculture production, and farmers' income. It concentrated on the assessment of the Sarawak aquaculture sector. Sarawak is the biggest state in East Malaysia (in Borneo Island) and the total area is almost equivalent to the total area of Peninsular Malaysia. The geographical location of Sarawak provides good potential for the development of the aquaculture industry, and has been identified as being among the major industries in the Sarawak Corridor of Renewable Energy (SCORE). There are 21 potential river basins for aquaculture activities located in the 11 divisions of Sarawak. Each division has different meteorological features and environmental challenges for the development of the aquaculture sector that may give rise to the different aspects of the biophysical vulnerability assessment results. Furthermore, the administration and legislation control of the aquaculture sector in Sarawak is unique and different to the other states. This may cause a significant difference to policy implications concerning adaptation to climate change.

Using secondary data, multiple linear regression is employed as one of the environmental impacts assessment techniques (Barthwal, 2002; Basu & Lokesh, 2014) to identify the significant relationship between the climate change risk factors with aquaculture production. The log-linear model is used in this study to remove the systemic change or variance of errors that may have the problem of heteroscedasticity, and, at the same time, linearize the relationship between the dependent and independent variables. The log-linear regression model for each aquaculture system is:

$$\ln\ prod_t = \alpha + \beta_1 \max t_t + \beta_2 \min t_t + \beta_3 rain_t + \beta_4 humid_t + \beta_5 sun_t + \beta_6 area_t + \mu_t \quad (1)$$

Where,

$prod_t$ = total annual production in tons for each aquaculture systems

$\beta_1 \max t_t$ = mean maximum temperature in °C

$\beta_2 \min t_t$ = mean minimum temperature in °C

$\beta_3 rain_t$ = mean total rainfall in mm per day

$\beta_4 humid_t$ = mean percentage of relative humidity

$\beta_5 sun_t$ = total hours of sunshine per day\

$\beta_6 area_t$ = total area of aquaculture ponds in hectare (ha) or cages in m^2.

The data for total annual aquaculture production and total aquaculture area were gathered from the Agricultural Statistics of Sarawak, Department of Agriculture Sarawak, and the Annual Fisheries Statistics, Department of Fisheries Malaysia, from 1992 to 2009. The data covered four different aquaculture systems, known as freshwater ponds, freshwater cages, brackish water ponds, and brackish water cages systems. The climate data for the same period were gathered from the Yearbook of Statistics, Department of Statistics Malaysia, Agricultural Statistics of Sarawak, Department of Agriculture Sarawak, and from the Malaysian Meteorological Department, Kuala Lumpur.

Primary data were gathered from a questionnaire survey using face-to-face interview with 255 aquaculture farmers in Sarawak, East Malaysia, using the stratified sampling method. However, only 249 were qualified and fulfilled the selection criteria of individual aquaculture farms. Apart from the demographic items, the total annual production and total aquaculture income of each farmer were also included. There are 11 climate change risk assessment items in the questionnaires (attached in the appendices) to identify the farmers' feedback concerning the effect of climate change risks factors on their production. The second analysis employed bivariate analysis of Spearman's rho correlation to identify the strength and direction of linear relationship between the total production and total aquaculture income with the climate change risks factors that affect aquaculture production.

This technique was applied because data were collected and ranked (non-parametric nature), and had violated the assumptions of normally distributed data of parametric analysis (Field, 2009).

FINDINGS AND DISCUSSION

The econometric model (1) for all the aquaculture systems was estimated using the ordinary least squares (OLS) estimation technique, and estimations were carried out using e-views 6.0. The findings in Table 1 were compared by types of water (freshwater and brackish water) results and different systems of aquaculture, known as pond and cage aquaculture systems. The assumptions of multiple linear regressions were fulfilled, as it was found that the estimated residuals of all the aquaculture systems were normally distributed. There was no evidence of autocorrelation from the Breusch-Godfrey LM test and no evidence of heteroscedasticity from the White test for any of the estimated equations for the aquaculture systems.

Table 1
Climate variability relationship in freshwater and brackish water aquaculture productions in Sarawak

Variables	Freshwater pond	Freshwater cages	Brackish water ponds	Brackish water cages
C	-48.35 (-1.74)	127.9073 (1.32)	-21.47 (-0.74)	-19.1145 (-0.58)
$Maxt_t$	0.8267 (1.17)	-4.1772 (-1.44)	1.2444 (1.65)	-0.6452 (-0.66)
$Mint_t$	0.8823* (2.02)	0.4612 (0.32)	0.2115 (0.40)	0.8164 (1.40)
$Rain_t$	0.0919 (1.35)	0.1839 (0.73)	-0.0775 (-1.13)	0.0192 (0.20)
$Humid_t$	0.0248 (0.52)	-0.0327 (-0.25)	-0.1063*** (-3.31)	0.2045 (1.52)
Sun_t	0.7940 (0.94)	-0.6264 (-0.20)	-1.2674 (-1.47)	0.9354 (0.78)
$Area_t$	0.0014 (-1.74)	0.0000 (0.74)	0.0030*** (5.57)	0.0002** (2.74)
R-squared	0.57	0.29	0.91	0.79
Adjusted R-squared	0.33	-0.10	0.86	0.67
Standard error of regression	0.66	2.35	0.69	0.89
Sum of squared residuals	4.77	60.67	5.22	8.76
F-statistic	2.41	0.73	17.84	6.81
Serial correlation	1.07	0.86	0.85	1.11
Heteroscedasticity	0.28	0.49	0.55	1.60
Normality	0.65	3.89	0.57	1.31

Notes: * significant at the 10% level; ** significant at the 5% level; *** significant at 1% level

The R^2 value showed that 57% of total production in the freshwater pond aquaculture system was explained by the variation in the observed independent variables. In freshwater cages, the R^2 value verified that 29% of total production was explained by the variation in the observed independent variables. The estimated regression results for the brackish water ponds explained that 91% of total production was explained by the variation in the independent variables. The R^2 value in the brackish water cages regression results indicated that about 79% of the variation in total production was explained by the variation in the explanatory variables.

The log-linear model regression results showed that the mean minimum temperature had a statistically significant impact on the freshwater aquaculture pond production. However, no explanatory variables had a significant effect on the freshwater cage aquaculture production. In the freshwater aquaculture system, the climate indicators, especially temperature, mostly influenced the total production. Water temperature affects the quantity of oxygen dissolved in the water, evaporation, and aquaculture productivity directly (Kutty, 1987). Hence, the aquaculture species grew dynamically in the optimal minimum and maximum tolerance limits of temperature. However, rapid temperature variation will have a negative effect on the aquaculture species growth due to less dissolved oxygen in the warm water. The change of temperature will change the feeding pattern, nutrients, and growth of the fish because it doubles the rate of metabolism, chemical reaction, and oxygen consumption (Tidwell et al., 1999). The fish will experience stress and disease threat when the temperature increases to the maximum tolerance or fluctuates suddenly. Modification of the biophysical condition due to temperature will affect production or result in unproductive growth of the fisheries. It will reduce the returns of aquaculture production to farmers and increase the operational costs of farms.

The effects of some biophysical factors of climate change are clearly indicated in the brackish water aquaculture system. The results showed that the mean relative humidity had a negative significant relationship to brackish water pond aquaculture, while the total area was significant to both the brackish water pond and cage production. An increase of 1% in mean relative humidity will decrease the total production for brackish water ponds by 10.63%. The negative impact of mean relative humidity is consistent with the study done by Kutty (1987). Air humidity has a significant relation to the level of evaporation of the water in the ponds and cages. If the degree of humidity increases, evaporation will decrease. This will cause an increase in moisture of the cultured species, the volume of fish food and the use of chemicals in aquaculture activities.

In addition, an increase of one hectare of total area will increase the total brackish water pond aquaculture production by 0.30%. An increase in the area of brackish water aquaculture cages by $1m^2$ increases aquaculture production by 1.92%. The data on total aquaculture production in Sarawak showed that the brackish water ponds production was low compared to freshwater pond production in that it only covered 1,158.37 hectares of land.

The pond aquaculture activities in Sarawak were mostly concentrated in freshwater pond activities in inland areas due to the geographical factors in that there are many rivers and small streams, and the water supply is naturally replenished from regular rainfall. The brackish water pond activities require high management costs to ensure sufficient water supply into the ponds from the coastal areas and estuaries. Moreover, the positive relationship of total aquaculture area in brackish water ponds and cages suggests that additional cages and ponds will result in higher production in this sector.

The climate change effect is greater in the pond aquaculture system than in the cage system, as pond aquaculture system is more sensitive to changes in temperature and humidity because such systems are conducted in a controlled environment (stored water) and depend on or are influenced by the soil content. The water quality problem is a major concern in the pond system due to the aforementioned reasons. The impact of climate change risks to cage aquaculture is less compared to pond aquaculture because the activities are operated in the natural and open water access of the rivers. The natural ecology of the river reduces the impacts of climate variability exposure that harms fish growth. However, areas for aquaculture cages are very limited due to inadequate suitable locations and competition from other marine activities.

This study involved 224 male and 25 female respondents of which 1.6% were aged less than 24 years old, 5.2% were aged between 25 and 34 years old, 17.7% were aged between 35 and 44 years old, 30.9% were aged between 45 and 54 years old, 30.5% were aged between 55 and 64 years old, and 14.1% were aged above 65 years old. The majority of the survey respondents (103 respondents) were from Bumiputera groups, such as Bidayuh, Iban, Bisaya, Lunbawang, and Kedayan, 80 Chinese respondents, and 66 Malay respondents. As to the type of aquaculture system, 51 respondents were involved in brackish water cage aquaculture, 13 respondents in brackish water pond aquaculture, 31 respondents in freshwater cage aquaculture, and the majority of the respondents (154) were involved in freshwater pond aquaculture.

The relationship of climate change risks to aquaculture production and total income of farmers in Sarawak is explained by the Spearmen's rho correlation results of the survey (Table 2). The results generally explain that all the climate change risk factors that are significant to the total aquaculture production and total income of farmers have a low and negative correlation between the observed variables. The results indicate that total aquaculture production is negatively significantly correlated with pH increase, temperature increase, dissolved oxygen, non-pandemic disease, pH decrease, and temperature decrease. Meanwhile, the total aquaculture income of farmers has a negative significant correlation with temperature increase, temperature decrease, dissolved oxygen, and high wave.

The negative correlation between all significant factors verify that the increment frequency of climate change risks factors, such as pH increase and decrease, water temperature increase and decrease, dissolved oxygen decrease, and pandemic and non-pandemic disease increase causes a decrease and production loss in total aquaculture production. Meanwhile, increase

Table 2

Spearman's rho correlation results of climate change risks drivers to aquaculture production and total income of farmers

Factors	pH inc	pH dec	rain	Temp. inc	Temp. dec	Dissolved O_2	Drought	Flood	High wave	Pandemic	Non-pandemic
Total Production	-.150* (.017)	-.179** (.005)	-.066 (.302)	-.152* (.016)	-.172** (.007)	-.185* (.003)	-.004 (.952)	.089 (.159)	-.054 (.401)	-117 (.065)	-.125* (.048)
Total income	-.086 (.174)	-.123 (.052)	-.105 (.099)	-.150* (.018)	-.133* (.036)	-.251** (.000)	.006 (.930)	.047 (.461)	-.130* (.041)	-.081 (.203)	-.091 (.151)

Notes: *. Correlation is significant at the .05 level (1-tailed); **. Correlation is significant at the .01 level (1-tailed) events of temperature increase, temperature decrease, dissolved oxygen, and high wave reduce the total aquaculture income of farmers. The findings support that water quality is one of the important factors influencing aquaculture growth. Aquaculture species are sensitive to water temperature and the change in temperature will change the feeding pattern, nutrients, and growth of fish because it doubles the rate of metabolism, chemical reaction, and oxygen consumption (Tidwell et al., 1999). A change in temperatures modifies the quantity of dissolved oxygen level in the water and can cause fish death. If an increase in the pH and temperature in aquaculture water bodies occur, their reaction will further exacerbate the ammonia toxicity problem, which will then reduce production and increase the chance of diseases outbreaks.

These results highlight the impact of climate change on the aquaculture sector in Sarawak. It is found that the impact of climate change risks is moderate in the aquaculture sector in Sarawak. However, the impact of the frequent occurrence of climate change events in the future will increase the socio-economic vulnerability of farmers' livelihoods if there is no further effective preventive and adaptive action to minimize the impact.

CONCLUSION

As one of the main industries in the SCORE development, efforts to enhance sustainable aquaculture production are pertinent and essential. Although the impact of climate change risks to aquaculture farmers in Sarawak is still moderate and tolerable, it is important to identify the potential adaptation capacity and capability of farmers to cope with the risks. The occurrence of events and level of risks of climate change in the future are unpredictable. Thus, an early vulnerability assessment study is important to indicate the possible action needed to mitigate the potential risk, and, at the same time, assist the potential adaptation strategies in coping with the future climate change risk. This study focused primarily on the physical and ecological stressors of climate change to the aquaculture production and farmers' income. Admittedly, socio-economic factors such as age, ethnicity, and other related factors will determine the growth of the aquaculture sector and help increase the adaptive capacity and resilience of farmers to climate change risks. The effective adaptation strategies can be achieved by the co-operation and responsible actions of all stakeholders in aquaculture production. At the farm level, green technology application, training and consultancy, and good aquaculture management practice may help the farmers to reduce the impact of climate change risks. At the sector level, there is a need for a research and development centre for monitoring the climate, water quality, and diseases in a consistent way that focuses on the aquaculture sector in Malaysia. Meanwhile, at the national level, it is important to ensure the effectiveness of government assistance schemes and programmes for farmers, and eliminate the leakage of funds by intermediary agents or suppliers in supplying the quality inputs to the farmers. Future study may explore the role of socio-economic factors and demographic factors in identifying the differences of climate change risks exposure and adaptive capacity among aquaculture producers. Nevertheless, the current study has contributed towards the formulation of policy guidelines especially in identifying the cost and benefits of implementing adaptation strategies that are necessary to the aquaculture sector in Malaysia to cope with the climate change risks in the future.

ACKNOWLEDGEMENT

The authors would like to thank the State Planning Unit, Sarawak for permission to do research, the Inland Fisheries Division, Department of Agriculture, Sarawak, the Department of Marine Fisheries, Sarawak and Natural Resources & Environmental Board, Sarawak for the assistance in data collection and University of Malaya and University Malaysia Sarawak for providing the research financial supports.

REFERENCES

Allison, E. H., & Horemans, B. (2006). Putting the principles of the Sustainable Livelihoods Approach into fisheries development policy and practice. *Marine Policy, 30*(6), 757-766.

Barange, M., & Perry, R. I. (2009). Physical and ecological impacts of climate change relevant to marine and inland capture fisheries and aquaculture. In K. Cochrane, C. De Young, D. Soto, & T. Bahri (Eds.), *Climate change implications for fisheries and aquaculture* (pp. 7-106). Rome: Food and Agriculture Organization of the United Nations [FAO].

Barthwal, R. R. (2002). *Environmental impact assessment*. New Delhi: New Age International (P) Limited Publishers.

Basu, S., & Lokesh, K. S. (2014). Application of multiple linear regression and manova to evaluate health impacts due to changing river water quality. *Applied Mathematics*, *5*(05), 799-807.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). *At risk: Natural hazards, people's vulnerability and disasters*. London: Routledge.

Brooks, N. (2003). *Vulnerability, risk and adaptation: A conceptual framework* (Tyndall Centre for Climate Change Research Working Paper No. 38). Norwich: University of East Anglia.

Chu, C., Mandrak, N. E., & Minns, C. K. (2005). Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. *Diversity and Distributions*, *11*(4), 299-310.

Daw, T., Adger, W. N., Brown, K., & Badjeck, M. C. (2009). Climate change and capture fisheries: Potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto, & T. Bahri (Eds.), *Climate change implications for fisheries and aquaculture* (pp. 107-150). Rome: Food and Agriculture Organization of the United Nations [FAO].

Department of Fisheries. (2004). *Annual fisheries statistics.* Kuala Lumpur, Malaysia: Department of Fisheries.

Department of Fisheries. (2013). *Annual fisheries statistics.* Kuala Lumpur, Malaysia: Department of Fisheries.

De Silva, S. S., & Soto, D. (2009). Climate change and aquaculture: Potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto, & T. Bahri (Eds.), *Climate change implications for fisheries and aquaculture* (pp. 151-212). Rome: Food and Agriculture Organization of the United Nations [FAO].

Edwards, P. (2000). Aquaculture, poverty impacts and livelihoods. *Natural Resource Perspectives, 56*(8), 1-4.

Field, A. (2009). *Discovering statistics using SPSS* (3rd ed.). United Kingdom: SAGE Publications Ltd.

Food and Agricultural Organization [FAO]. (2011). *Implications of climate change on fisheries and aquaculture: Challenges for adaptation and mitigation in the Asia-Pacific Region* (APFIC/FAO Regional consultative workshop. RAP Publication 2011/17). Bangkok: FAO Regional Office for Asia and the Pacific.

Hambal, H., Mohd. Akhir, A., & Saniah, Y. (1994). *Environmental issues on aquaculture development in Malaysia*. Malaysia: Fisheries Research Institute, Department of Fisheries.

Idris, K., Mohamed Shaffril, H. A., D'Silva, J. L., & Man, N. (2013). Identifying problems among seabass brackish-water cage entrepreneurs in Malaysia. *Asian Social Science*, *9* (9), 249-256.

Intergovernmental Panel on Climate Change [IPCC]. (2007). *Climate Change 2007: Synthesis Report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Kelly, P. M., & Adger, W. N. (1999). *Assessing vulnerability to climate change and facilitating Adaptation* (Centre for Social and Economic Research on the Global Environment Working Paper GEC 99-07). Norwich: University of East Anglia.

Kutty. M. N. (1987). *Site selection for aquaculture: Climatic factors* (African Regional Aquaculture Centre Working Paper ARAC/87/WP/12(3)). Port Harcourt, Nigeria: African Regional Aquaculture Centre.

Ministry of Finance. (1998). *Economics report 1998*. Kuala Lumpur, Malaysia: Ministry of Finance.

Ministry of Finance. (2010). *Economics report 2010*. Kuala Lumpur, Malaysia: Ministry of Finance.

Ministry of Finance. (2011). *Economics report 2011*. Kuala Lumpur, Malaysia: Ministry of Finance.

Mohanty, B. P., Mohanty, S., Sahoo, J. K., & Sharma, A. P. (2010). Climate change: Impacts on fisheries and aquaculture. In S. Simard (Ed.), *Climate change and variability* (pp. 119-138). Croatia: InTech Publishing.

O'Brien, K., Sygna, L., & Haugen, J. E. (2004). Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway. *Climatic Change, 64*(1), 193-225.

Schjolden, A. (2004). *Towards assessing socioeconomic impacts of climate change in Norway-Sensitivity in the primary sectors: Fisheries, agriculture and forestry* (CICERO Report 2004:03). Oslo, Norway: Center for International Climate and Environmental Research.

Tidwell, J. H., Coyle, S. D., Evans, J., Weibel, C., McKinney, J., Dodson, K., & Jones, H. (1999). Effect of culture temperature on growth, survival and biochemical composition of Yellow Perch Perca flavescens**.** *Journal of the World Aquaculture Society, 30*(3), 324-330.

World Bank. (2010). *World development report 2010: Development and climate change*. New York: World Bank.

World Bank. (2013). *Fish to 2030: Prospects for fisheries and aquaculture* (Agriculture and Environmental Services Discussion Paper No. 03, World Bank report number 83177-GLB). Washington: World Bank.

WorldFish. (2007). *Fisheries and aquaculture can provide solutions to cope with climate change* (Issue Brief No, 1701). Penang, Malaysia: The WorldFish Center.

APPENDIX

SURVEY ON THE VULNERABILITY AND ADAPTATION TO CLIMATE CHANGE IMPACTS IN SARAWAK'S AQUACULTURE SECTOR.

Instruction: Please (√) or fill up the questionnaires items with neccesary details.

SECTION A: RESPONDENTS BACKGROUND

A1 Age: ________ years old

A2 **Gender :** ☐ Male ☐ Female

A3 **Race :** ☐ Malay ☐ Chinese ☐ Indian
☐ Bumiputera. Please specify : _______ ☐ Others. Please specify: ______

A4 **Marital Status :** ☐ Single ☐ Maried ☐ Widower / widow / divorced

A5 **Highest qualifications:** ☐ No school ☐ Primary school ☐ Lower secondary school
☐ High secondary school ☐ Certificate / diploma ☐ Degree ☐ Others: Please specify: _______

SECTION B: FARMERS' ASSETS OWNED INFORMATION

B1 **Types of aquaculture system:** ☐ freshwater pond ☐ freshwater cages
☐ brackish water pond ☐ brackish water cages

B4 **Total aquaculture production per year**
First cycle : ______________
Second cycle : ______________
Third cycle : ______________
Total : ______________

B5 **Total aquaculture income per year**
First cycle : ______________
Second cycle : ______________
Third cycle : ______________
Total : ______________

SECTION C: CLIMATE CHANGE IMPACTS ASSESSMENT

C1 Choose the percentage rank of your production loss due to the listed climate change risks. Please state the frequency of the related climate change risks events occured in a year at your aquaculture site.

Climate change risk	Yes and average percentage of the production loss (%) due to the impact					No effect	Not related	Frequency in a year
	1 – 20	21 – 40	41 - 60	61 - 80	81 - 100			
pH water increase	☐	☐	☐	☐	☐	☐	☐	_______
pH water decrease	☐	☐	☐	☐	☐	☐	☐	_______
Long raining period	☐	☐	☐	☐	☐	☐	☐	_______
Water temperature increase from the tolerance limit	☐	☐	☐	☐	☐	☐	☐	_______
Water temperature decrease from the tolerance limit	☐	☐	☐	☐	☐	☐	☐	_______
Dissolved oxygen in water decrease	☐	☐	☐	☐	☐	☐	☐	_______
Long drought seasons	☐	☐	☐	☐	☐	☐	☐	_______
Floods event	☐	☐	☐	☐	☐	☐	☐	_______
Severe and high wave	☐	☐	☐	☐	☐	☐	☐	_______
Pandemic disease problem	☐	☐	☐	☐	☐	☐	☐	_______
Non Pandemic disease problem	☐	☐	☐	☐	☐	☐	☐	_______