The Effects of Climate Variation on Fisheries and Coastal Aquaculture

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ABSTRACT

The two-part study was conducted to ascertain the effect of climate variation on growth of key aquaculture species, i.e. mud crab raised as soft-shell crab, and phytoplankton, a key food source for shellfish. Data were collected from the districts of Khlung, Laemsing and Thamai, Chanthaburi Province, Thailand, using structured questionnaire, to determine the effect of climate variation on coastal fisheries. The first part of the study showed that sea temperature could significantly alter the growth rates of both mud crab and phytoplankton ($p<0.05$). The optimal temperature for mud crab growth was between 30 and 33^{o}C, whereas growth rate of phytoplankton was highest with a shortest doubling time at 30^{o}C. However, if the temperature exceeded 32^{o}C, plankton population decreased with the rate declining with cascading effects on shellfish growth. The second part of the study revealed that fishers and aquaculture farmers perceived that climate variation affected their livelihoods including fisheries and aquaculture production. These climate variations included raining during non-rainy season, increased rain fall, severe waves, and changes in monsoon timing. In order to deal with climate variation events, fishing communities should listen to news regarding the weather before making decisions and should exchange information within their communities. Additionally, the government should develop an effective method for forecasting weather, rainfall, and freshwater runoff, and communication channels should be improved.

Keywords: climate variation, aquaculture, coastal fishery, phytoplankton, mud crab

INTRODUCTION

Climate variation has become more evident globally. Problems involving changes in water cycle, rising sea levels, sea surface temperature, and violent storms and waves have a tendency to occur in many areas. These climate variations have effects on the aquatic ecosystem, which in turn influences fishery productivity. Changes in sea surface temperature have impact on habitat and marine life histories and demography of population and species (Organisation for Economic Co-operation and Development, 2010), and may increase the incidence of diseases and parasites in marine organisms (Karvonen *et al*., 2010). Rising sea levels could contaminate ground water sources,

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and these changes all act to reduce the areas suitable for aquaculture. Increased intensity of storms will result in more severe wave action along the coast. The increasing frequency and severity of floods, storms and waves could damage fishing community infrastructure and reduce fishers' fishing opportunities (Organisation for Economic co-operation and Development, 2010; Badjeck *et al*., 2009).

Southeast Asia START Regional Center mathematical models used for rainfall change dynamics prediction indicated that climate variations will increase the annual average rainfall in Eastern Thailand by 300-500 millimeters (mm), resulting in the highest rainfall in the country. The effects of this will be increased flooding and changes to the salinity of the ocean water, with severe consequences for aquaculture (Chinvanno and Snidvongs, 2007). Besides that, a report of the Thai Meteorological Department (2010) found that the average rainfall in Eastern Thailand, at approximately 1,998.5 mm, is higher than the annual average rainfall for Thailand. This indicates that Eastern Thailand is a vulnerable area to climate variation.

Utilization activities on the east coast of Thailand are fisheries and coastal aquaculture. In particular, the estuary and the coast in Khlung, Laemsing and Tha Mai districts in Chanthaburi province are key areas for oyster, blood cockle, green mussel and soft-shell mud crab culture (Kantungkul *et al*., 2012). But coastal erosion in the area is severe. The damage from coastal erosion could reach up to 35.21 km along the shore, at the rate of over 5 meters per year (Department of Marine and Coastal Resources, 2011). Additionally, comparison of the surface water temperature of the Wain Estuary in August 2001 (Srisomwong, 2003) and August 2011 (Kantungkul *et al*., 2012) demonstrated that the average sea temperature had increased $1^{o}C$ over the past ten years. This temperature change may be the first sign of climate change in the area.

If climate variation occurs on a large scale in the area, the fishing community whose livelihoods depend on natural resources, may be affected adversely. There is an urgent need to understand climate variation and the impacts it will have on fishery and aquaculture. However, currently there are few resources available for research into this area. Focusing research efforts into climate variability will also allow for the development of policies to establish an approach incorporating adaptation to climate variability of fishers and farmers in order to achieve improvement in the economic potential of fish aquaculture in Eastern Thailand.

The objectives of this study are as follows:

1. To ascertain climate variation impacts on the growth of key aquaculture species; and,
2. To ascertain the effects of climate variation on coastal fisheries

METHODS

Climate variation impact on the growth of key aquaculture species

It is necessary ultimately to ascertain growth of all economically important marine species. Main species in coastal aquaculture in Khlung, Laemsing and Tha Mai Districts, Chanthaburi province, are oyster, blood cockle, green mussel and mud crab (Kantungkul *et al*., 2012). This study focused on the growth of mud crab cultured to produce soft-shell crab, and on the growth of phytoplankton which are shellfish feed.

Sea temperature effects on growth of mud crab

The experiment was run using a complete randomized design. Mud crab used in the study were all obtained from the same farm and allowed to molt overnight before the start of the experiment. Their weights ranged from 94–115 grams. Each crab was placed in an 8 x 6 x 6 inch plastic basket. Eight baskets were submerged into approximately 4 inches of water in the tank. There were three water temperature treatments 27, 30 and 33°C. Water salinity was maintained at 20 psu which is optimal for mud crab growth (Kantungkul *et al.*, 2012). Water temperature was controlled using water-cooling and heating systems. Each week, 50% of the water was removed and replaced with new water. Crabs were fed a diet of yellow-stripe scad every other day. When molting occurred, weight and carapace width were recorded. The experiment was run for a period of four months.

The growth of mud crab was calculated as follows:

$$\text{Growth rate} = \frac{\text{(weight after molting - begining weight)}}{\text{Time since molting}}$$

Sea temperature effects on phytoplankton growth

The phytoplankton, *Chaetoceros* sp., was used in this study as an indicator of shellfish food availability. A similar experimental setup was employed, with three replicates of three temperature treatments: 28, 30 and 32°C. The average temperature of surface water in the study area during 2007-2013 was 29.8±1.8°C (Ministry of Natural Resources and Environment, 2013). Thus, the temperature treatment in this study was focused on 2°C variation from the average which covered the surface water temperature occurring in the area during 2010-2015. The plankton was placed in 250 mL glass bottles, with a density of approximately 15 x 10^6 cells/mL. The ESM medium (140 ml) was added, and fluorescent lighting with an intensity of 8,000 lux was provided. On days 1, 2, 3, 5 and 7, samples were randomly selected from each treatment throughout the day, and the number of phytoplankton was recorded using a Sedgewick-Rafter.

The growth of phytoplankton was calculated as follows:

$$\mu = \frac{(lnN_2 - lnN_1)}{t_2 - t_1}$$

where N_1 is the density of the phytoplankton at the staet of the trial (t_1) and N_2 is the density of phytoplankton at the end of the trial (t_2).

The period of time required for phytoplankton to double its cell numbers, called doubling time, was calculated from $t_a = 0.6931/\mu$.

The impacts of climate variation on coastal fisheries

Understanding the impacts of climate variation on coastal fisheries requires understanding of how fisheries are used, for example, how fisheries are currently managed and how the key fishery species are raised. Research efforts should also focus on understanding indigenous knowledge of fishing communities regarding climate variation and the impacts they think it may have on their fisheries. The areas under this two-year study were Bang Chan, Khlung, Kwian Hak, Laemsing, Pak Nam, Takat ngao, Tha Mai and Wan Yao districts.

Fishing community livelihoods at the family level include families that do fishing and aquaculture as a profession. Thai fisheries statistics listed the total number of fishers and aquaculture farmers as 344 families (Department of Fisheries, 2010). Stratified random sampling was used to cover fishers and aquaculture farmers in the areas studied. The calculation of sample size for estimating the ratio of population at 95% confidence level allowed for 10% error (Thompson, 1992) The ratio of fishers to aquaculture farmers was 51 to 49. Structured interviews were carried out with 75 cases.

Data analysis

Climate variation impacts on the growth of key aquaculture species

Statistical analysis on the effect of sea temperature on the growth rate of mud crabs was conducted using analysis of variance (ANOVA) technique and comparison of means using Duncan's new multiple range test (Duncan). Statistical analysis on the effect of sea temperature on the growth rate of phytoplankton was conducted using multivariate analyses of variance (MANOVA), Wilk's Lamda statistic and ANOVA.

The impact of climate variation on coastal fisheries

Analysis to assess the effects of climate variation on coastal fisheries was conducted by comparing differences in attitude towards the effects of climate variation amongst groups of fishers and fish farmers. The T-test was used for comparison where the data are normal distribution, and where the data are not normally distributed, a Mann-Whitney test statistic was used.

RESULTS

Climate variation impacts on the growth of key aquaculture species

Sea temperature effects on growth of mud crab

Crabs raised in 33°C water had the highest average growth rate, at 0.86 g per day, whereas those in 27°C water had the slowest growth rate. Lower seawater temperature resulted in low metabolism and less food consumption, which further led to slower molting and less growth ($p = 0.008$; Table 1). Chen and Chia (1996) compared the effects of 25°C and 35°C on mud crabs, *Scylla serrata* and demonstrated that increasing temperature increases the rate of energy use. However, the growth rates of crabs raised in 30 and 33°C water were not significantly different ($p > 0.05$; Table 1).

Sea temperature effects on phytoplankton growth

An overall effect of sea temperature on the density of phytoplankton (Wilk's Lamda = 4.640, $p = 0.01$) was observed. Investigation into the effects of temperature

Table 1. Time since molting and growth rate of mud crab (g/day) at different water temperature

Water temperature (^oC)	Replicate	Time since molting (days)			Growth rate (g/day)	F	P
		Mean (±SD)	Min	Max	Mean (±SD)		
27	6	101 ± 22	70	127	0.24 ± 0.23^a	7.533	0.008**
30	3	98 ± 29	68	125	0.69 ± 0.38^b		
33	6	71 ± 8	63	78	0.86 ± 0.27^b		

Note *p< 0.05 and **p < 0.01. Characters a, b and c indicate statistical significance, where the same characters indicate that the differences are not statistically significant.

on the density of phytoplankton over time found that after 1 day, the density of phytoplankton did not differ significantly between treatments (p = 0.075). However, after 2 and 3 days, the average density of phytoplankton was significantly different between treatments (p = 0.000). The average density of plankton was greatest at 30^{o}C and at 5 and 7 days, and lowest at 32^{o}C (p = 0.002 and 001, respectively; Table 2). This is consistent with a study by Adenan *et al*. (2013), who found that the growth of diatoms (*Chaetoceros calcitrans*) and green algae was highest at 30^{o}C.

Seawater temperature affects the growth rate of phytoplankton and the time required for cells to double. Phytoplankton grown at 30^{o}C had the highest growth and required the shortest doubling time (Table 3). However, phytoplankton growth was reduced when temperature exceeded 32^{o}C, with likely consequences for the growth of shellfish.

Table 2. The effect of temperature on the density of phytoplankton over time

Day	Density of phytoplankton (Cells/mL) Mean ± SD			F	P
	28^{o}C	30^{o}C	32^{o}C		
1	$(1575.00x10^4)±(206.32x10^4)^a$	$(1524.67x10^4)±(323.99x10^4)^a$	$(1179.00x10^4)±(351.65x10^4)^a$	3.084	0.075
2	$(3529.00x10^4)±(616.76x10^4)^a$	$(4443.67x10^4)±(411.28x10^4)^b$	$(1940.33x10^4)±(374.11x10^4)^c$	41.887	0.000**
3	$(4458.67x10^4)±(741.46x10^4)^a$	$(5833.00x10^4)±(1054.91x10^4)^b$	$(2789.00x10^4)±(1069.94x10^4)^c$	14.899	0.000**
4	$(6972.00x10^4)±(727.37x10^4)^a$	$(7388.00x10^4)±(1439.73x10^4)^a$	$(4393.67x10^4)±(1530.39x10^4)^b$	9.579	0.002**
5	$(7897.00x10^4)±(1838.85x10^4)^a$	$(9727.33x10^4)±(2310.48x10^4)^a$	$(4794.00x10^4)±(1219.29x10^4)^b$	10.969	0.001**
6	$(1575.00x10^4)±(206.32x10^4)^a$	$(1524.67x10^4)±(323.99x10^4)^a$	$(1179.00x10^4)±(351.65x10^4)^a$	3.084	0.075
7	$(3529.00x10^4)±(616.76x10^4)^a$	$(4443.67x10^4)±(411.28x10^4)^b$	$(1940.33x10^4)±(374.11x10^4)^c$	41.887	0.000**

Notes: *p< 0.05 and **p < 0.01. The characters a, b and c appearing in each row indicate statistical significance in each day.

Table 3. Growth rates and time required for *Chaetoceros* sp. cells to double at different temperature treatments

Time (days)	Growth rate			Doubling time		
	28^{o}C	30^{o}C	32^{o}C	28^{o}C	30^{o}C	32^{o}C
1	0.81	1.07	0.50	0.86	0.65	1.39
2	0.52	0.67	0.43	1.33	1.03	1.61
4	0.37	0.39	0.33	1.86	1.76	2.11
6	0.27	0.31	0.23	2.58	2.24	2.96

The Effects of climate variation on coastal fisheries

Status of coastal fisheries

Understanding the effects of climate variation on coastal fisheries (fishing and aquaculture) requires the following information:

Of the coastal fishing communities sampled, 61% used gill nets, such as shrimp trammel nets, crab gill nets, Indo-Pacific mackerel gill nets, and mullet gill nets (Fig. 1). Fishing in Chanthaburi province occurs mostly at 3-5 km from the coastline, including in the Chanthaburi, Kem Noo and Wain estuaries, and in Chao Lao, Khlung and Ta Sang canals. Fishing is mostly carried out from long-tailed boats with lengths between 3-12 m, and with motors of 5-13 hp. These require 1-2 people per household who are unpaid labourers (94.4%; Fig. 2).

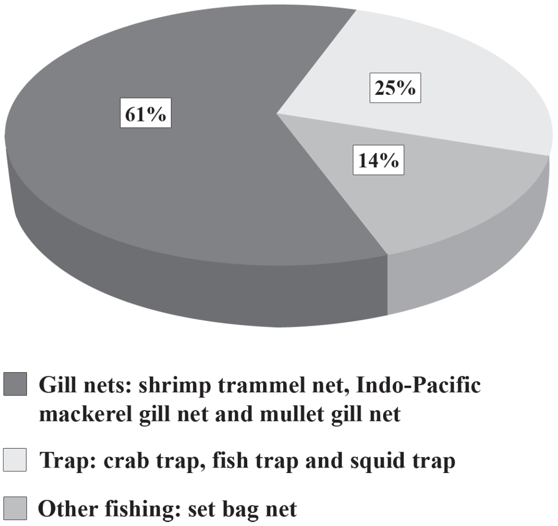

Figure 1. Types of fishing equipment used

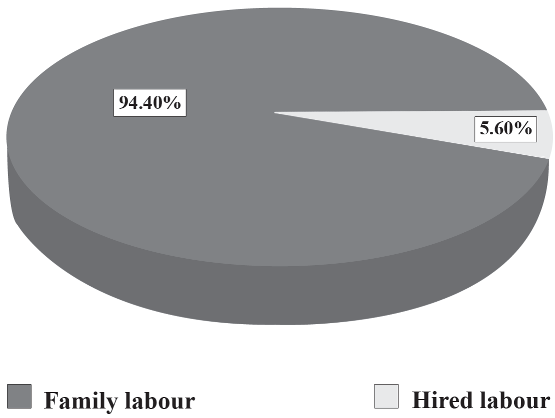

Figure 2. Types of labour in fisheries

The fishing gear can be used throughout the year. However, when waves and wind are too strong, or during monsoons, fishers are unable to go fishing. Table 4 shows the season and timing of fishing, as well as the catches for each fishing gear.

Table 4. Seasonal calendar of fishing activity, fishing periods and production

Fishing gear	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shrimp trammel nets	← Fishing all year (15-20 days/month) Production: Banana prawn 4-15 kg/day											→
Crab gill nets	← Fishing 6-30 days/month											→
	← Production: Blue swimming crab 10-20 kg/day		→	← Production: Blue swimming crab 5-10 kg/day						→	← Production: Blue swimming crab 10-20 kg/day	→
							← Monsoon and strong wind			→		
Mullet gill nets	← Fishing 6-20 days/month Production: Mullett 5-30 kg/day											→
Indo-Pacific mackerel gill nets	← Fishing 6-30 days/month Production: 5 kg/day						→	← Fishing 3-4 days/month Production 10-100 kg/day		→	← Fishing 20-30 days/month Production 200-300 kg/day	→
								← Monsoon and strong wind		→		

The main aquaculture species grown are blood cockle and oysters, although other species, such as green mussels, sea bass and mud crab, are also grown. Labour in aquaculture is provided by household members and hired labour. Aquaculture requires labourers to prepare land, make rafts, care for the shellfish, and harvest the products. Blood cockle culture is mostly done in Khlong Khlung Canal, Seung Canal, and Wain River. Oysters are raised from naturally available spat which attach on tocement posts placed by shellfish farmers. Most culture areas are in Bang Krachai, Kan Kow, Ma Muang and Ta Sang, canals, as well as the Wain River. Details of raising blood cockle and oysters are found in Table 5. Challenges in the culture of these species include maintaining the appropriate water salinity during the summer season (64.1%), suitable water quality (61.6%), and the reduction of wild stocks of shellfish species (56.4%). These are considered severe problems because there are still no solutions available.

Attitudes of fishers towards the effects of climate variation on fisheries

Climate issues

Three out of four respondents opined that climate variation would result in rain falling off season (75%). Rainfall was also expected to increase and result in flooding of fishing villages (66.7%). Both changes were expected to occur over relatively short

Table 5. Blood cockle and oyster culture systems

Details	Blood clam	Oysters from natural spat
Area of culture (Rai)	5-150 (Median = 27)	-
Plot size (m)	-	1.5 x 4 and 4 x 8
Water depth (m.)	1-3	2-4
Source of seed (province)	Chachoengsao, Chonburi, Petchaburi, Samut Prakan and Surat Thani	-
Stocking rate	125-333 kg/rai (Mean ± SD = 194 ± 85 kg/rai: size of seed 800-1000 ind. /kg)	Cement posts to collect shellfish spat 10,000–20,000 bundles per plot (1 bundle=10 strands)
Culture period/Production	8-16 months/200-250 kg/rai (size 80-100 ind/kg.)	3 months (July–September)/10,000-20,000 bundles per plot (1 bundle=10 strands)
Selling Price	20–35 Baht/kg.	0.4-1.0 Baht/strand.

time periods, with some respondents (58.3 and 50%, respectively) agreeing to this (Fig. 3). Nearly half of the respondents thought that they would be negatively affected by climate variation, especially by reduced rainfall in the rainy season (44.5%), and increased annual rainfall (41.7%) (Fig. 4). Although this rainfall was expected to occur over a relatively short period of time, the increasing frequency of flooding could affect the fishing villages and result in damaged properties. This is consistent with a study by the Organisation for Economic Co-operation and Development (2010) which briefed that more frequent and severely extreme events such as floods, storms and hurricanes would increase the vulnerability of fishing communities.

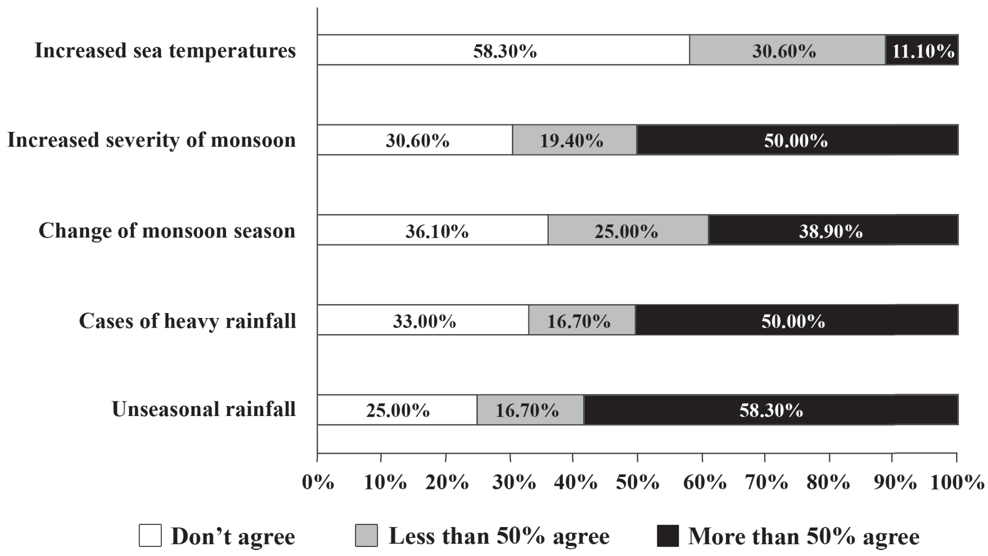

Figure 3. Attitudes of fishers to climate variation

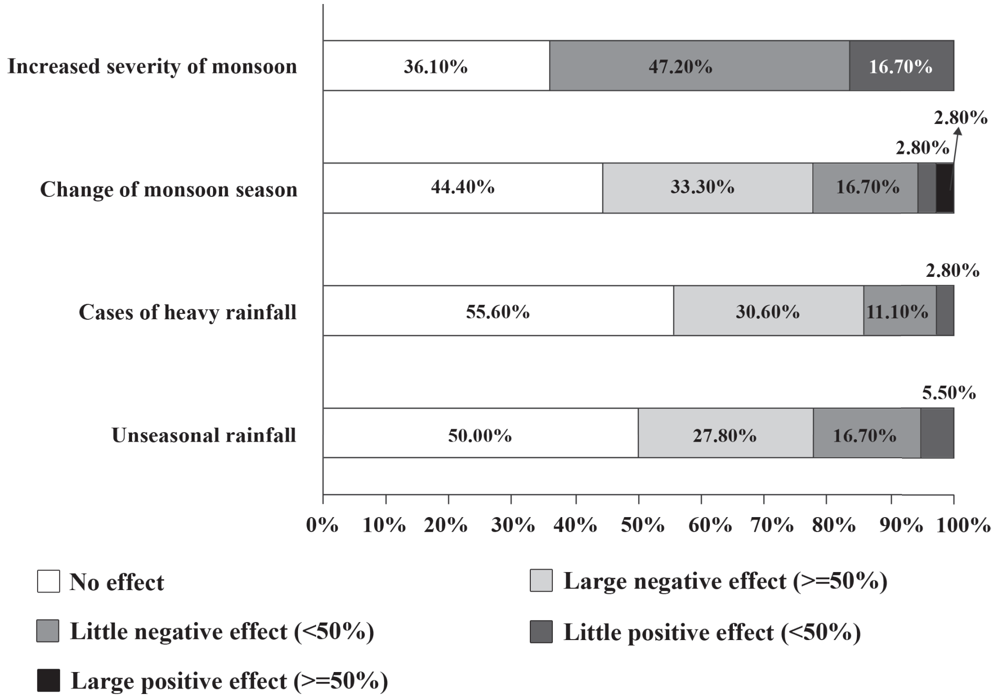

Figure 4. Effects of climate variation on fishers

More than half (63.9%) of the respondents perceived that the monsoon season would shift, with one in three respondents believing that this would happen at a high level. In the past, they could predict the arrival of the monsoon based on their experience. However, currently, they need information from climate stations to predict changes. An additional consequence of change may be increased severity of wind and waves during monsoons (69.4%) (Fig. 3). Half of the respondents (50.0%) thought that what could affect them negatively would be the occurrence of monsoon in some years which would be fast and frequent, while in other years, it would be slow (Fig. 4). During the monsoon season, fishing practices were forced to change. In order to adapt to marine species availability, fishers must change their fishing methods and sometimes they were unable to do so in time. In addition, during the monsoon season, there is increased severity of waves and wind. The majority (63.9%) of the respondents considered that this would have an effect, while 47.2% thought that this would have a negative effect due to the increased risk of fishing boats sinking. However, 16.7% of the respondents thought that these changes might be positive because it would increase the fishery resources (Fig. 4).

Changing sea temperatures is another change that people are aware of, with 33.3% expecting temperatures to rise, and 66.7% expecting no change. This is because this change is not so apparent yet (Fig. 3).

Study of natural resources, the environment and fisheries

With regards to fishery resources, 41.6% of the respondents perceived that climate variation would affect aquaculture species, while a third of the respondents (36.1%) perceived that the diversity of species would change. Meanwhile, 47.2% of the respondents opined that climate variation would have effects on the environment, such as the abundance of mangroves, due to strong waves and winds eroding the coast. Another 20% suggested that climate variation would result in changes in aquaculture sites, while in some places the number and size of sand bars or beaches would increase, in some other places, they would decrease. These changes would affect fisheries as follows: 3/4 of respondents thought that CPUE would change, with 27.8% thinking that fishing period would change. Approximately 61.1% perceived that the number of fishers and income from fishing would change (Fig. 5).

Climate variation is expected to affect resources, the environment and consequently fishing activity. A third of the respondents thought that this would affect the fish species (33.3%), with 13.9% believing this would have a positive effect and 19.4% believing that this would have a negative effect due to a reduction in species diversity in some areas and an increase in others (Fig. 6). Another 30.5% of respondents believed that climate variation would still affect the diversity of aquatic species, 22.2% of respondents believed that this effect would be positive and 8.3% believed that the effect would be negative. Climate variation also affects the sites available for fisheries, such that 16.6% believed they would experience these effects, with half believing that this would be negative and half positive (8.8%).

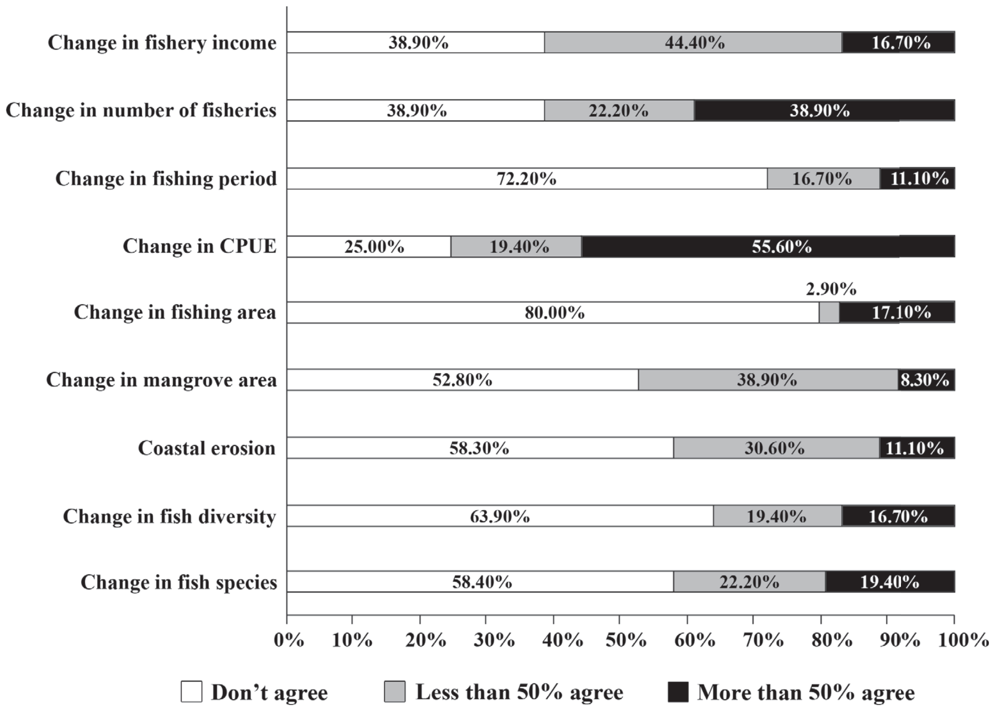

Figure 5. Attitudes of fishers to climate variation on resources, environment and fishing

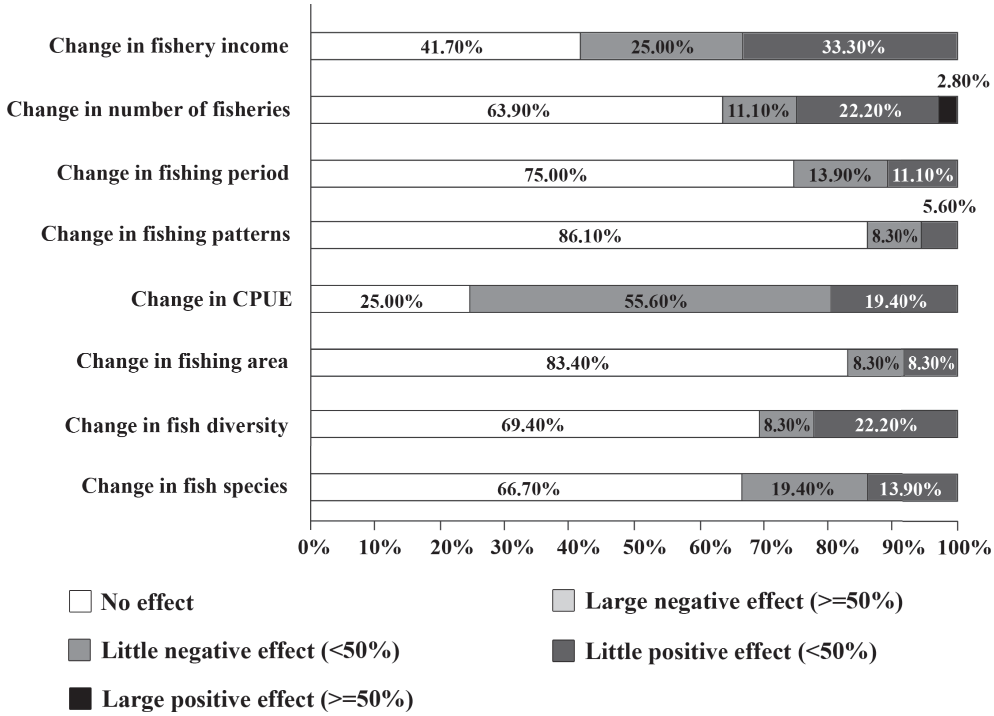

Figure 6. Effects of climate variation on fishing

This is because, in some places, this will cause the quantity of aquatic species to increase and in other areas this will cause them to decrease in number (Fig. 6). In addition to this, variation in climate would still cause changes of CPUE, where 55.6% of respondents believed that this would have a negative effect because there would be a reduction in marine stock, and they would not be able to go out and fish as often due to increased severity of waves and wind. It was perceived to have a positive effect by 19.4% because after monsoons, marine stocks tend to increase (Fig. 6).

Concerning negative impacts on fishing, 33.3 and 58.3% of respondents, respectively, believed that there would be an effect on the number of fishers and on their incomes. Negative impacts on fishers would occur due to the lack of labour and help from household members for fisheries work, increasing labour and fuel costs (Fig. 6). This is consistent with a study by Badjeck *et al*. (2009) who summarized the effects of climate variation on fishing communities as economic loss from increased costs required to access fishing grounds and the reduction in fish stocks.

However, some respondents believed that this would have a positive effect on fishing, as the resulting reduction in the number of fishers might increase per capita catches and income (Fig. 6).

Attitudes of aquaculture farmers towards the effects of climate variation on fisheries

Climate variation

Almost 3/4 of respondents believed that climate variation would impact rainfall, with 71.8% believing this would result in increased rainfall and 56.4% believing this would cause unseasonal rainfall to occur. Another 64.1% believed that climate variation would result in a shifting of the monsoon season and increased severity of waves and wind. In addition, 48.8% of respondents believed that during the winter months there might be unusual weather and 30.8% believed that the sea temperature would increase (Fig. 7).

Regarding the impact of climate variation on aquaculture farmers, approximately half of the respondents (53.8%) believed that climate variation would negatively affect them due to increased rainfall. The incidence of shellfish spat-fall would also increase, with 25.7% of respondents believing that climate variation would affect them during the monsoon season, due to the increased severity of waves and wind. Meanwhile, 74.3% did not think they would be affected because they are currently raising shellfish in canals (Fig. 8).

Moreover, the threat of rising sea temperature is another concern voiced by the respondents, with 28.2% believing that they would be negatively affected due to increased mortality of shellfish (Fig. 8). Shellfish farmers in the Wein River, and Khlung and Laemsing districts would be more heavily impacted than groups that raise shellfish in canals such as around Tha Mai district.

Aquaculture issues

A third of the respondents believed that there would be changes in the growth of shellfish (33.4%), survival rate (38.4%), and financial returns (33.3%) (Fig. 9).

Regarding the impact on aquaculture farmers, some respondents believed that climate variation would negatively impact shellfish growth (30.8%), shellfish survival rate (35.9%) and shellfish product and economic returns (28.2%) (Fig. 10).

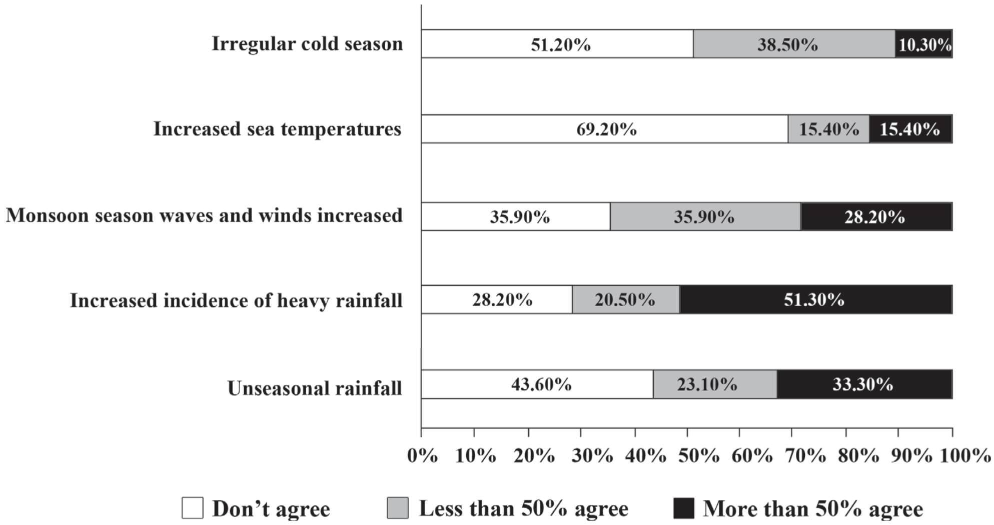

Figure 7. Attitudes of aquaculture farmers to climate variation

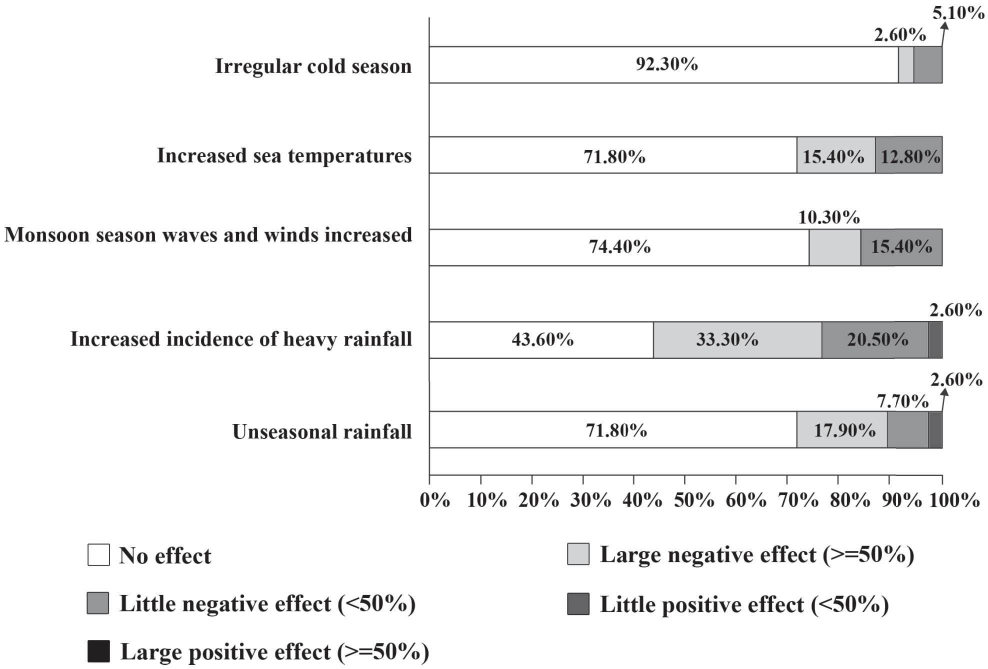

Figure 8. Effects of climate variation on aquaculture farmers

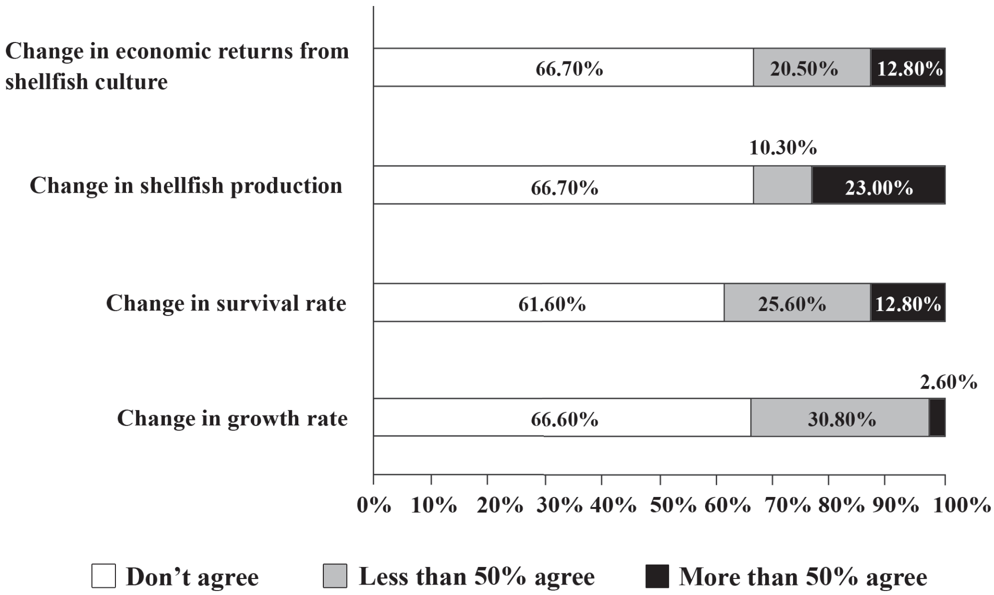

Figure 9. Attitudes of aquaculture farmers on effect of climate variation to their operations

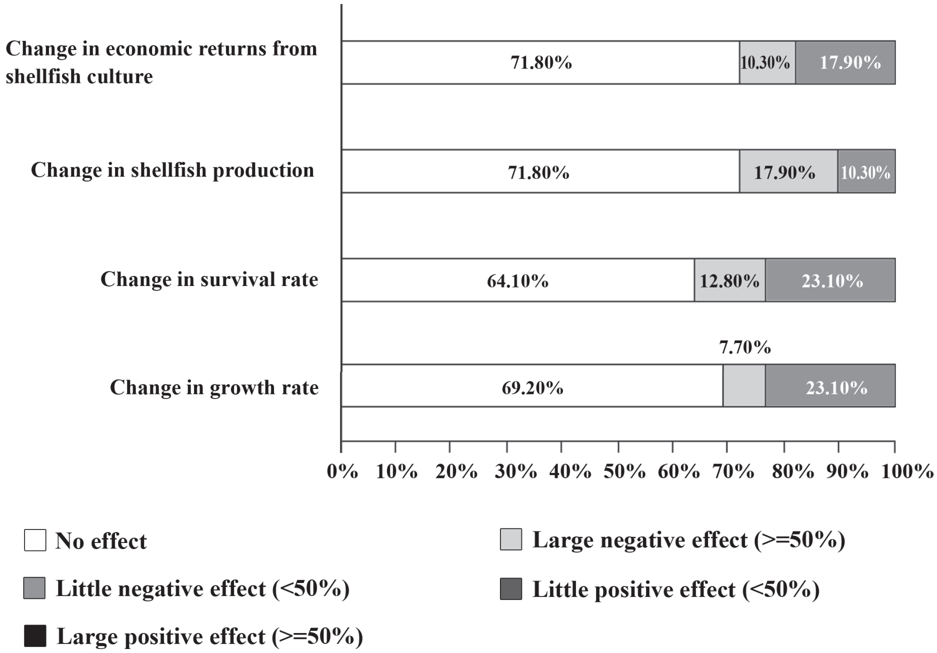

Figure 10. Effects of climate variation on aquaculture farmers

Overall effects of climate variation on fishers and aquaculture farmers

In summary, the attitude scores of fishers and aquaculture farmers towards the effects of climate variation are not statistically different ($|Z| = 0.222$, $p = 0.983$, and $|Z| = 0.495$, $p = 0.620$). The majority of fishers and aquaculture farmers believed that they would be affected only slightly by climate variation (86.1% and 87.1%, respectively) (Fig. 11 and Fig. 12).

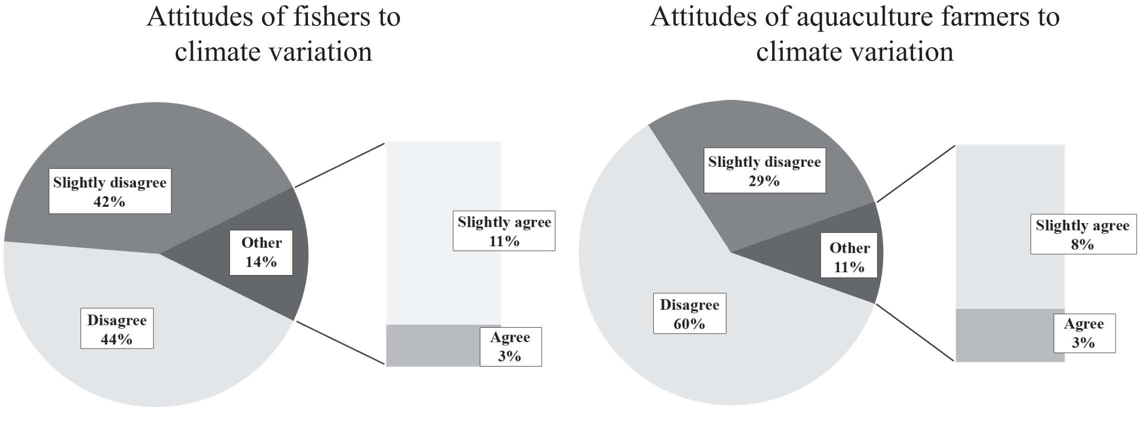

Figure 11. Attitudes of fishers and aquaculture farmers on climate variation and climate issues

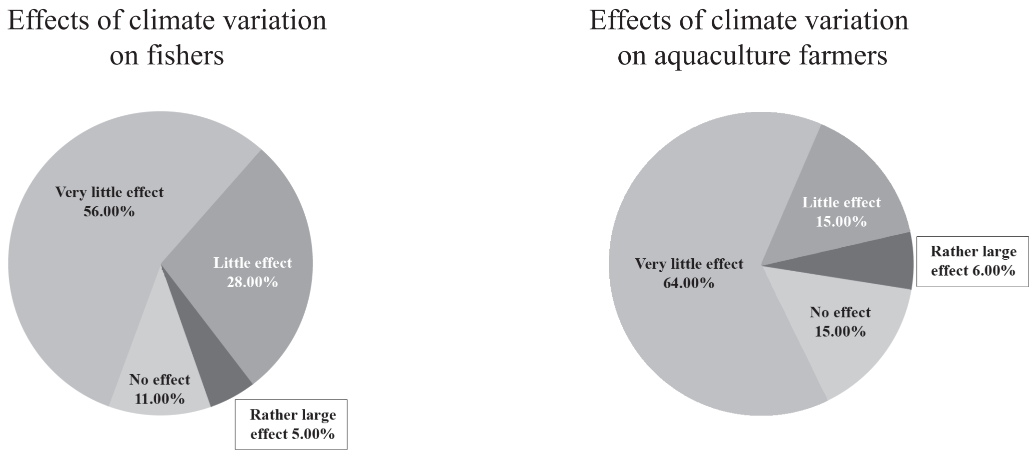

Figure 12. Effects of climate variation on fishers and aquaculture farmers

The majority of fishers perceived that resources, the environment and livelihoods would face challenges and that fishers would be affected (86.3% and 81.0%, respectively), which is different from aquaculture farmers ($|Z| = 3.019$, $p = 0.003$, and $|Z| = 3.381$, p -0.001), who did not think that their livelihoods would be challenged (35.8%) and affected (46.1%) (Fig. 13 and Fig. 14). This is likely to be because aquaculture farmers raise their shellfish in canals, and so may not experience changes in production compared to fishers who rely more heavily on natural resources and the environment.

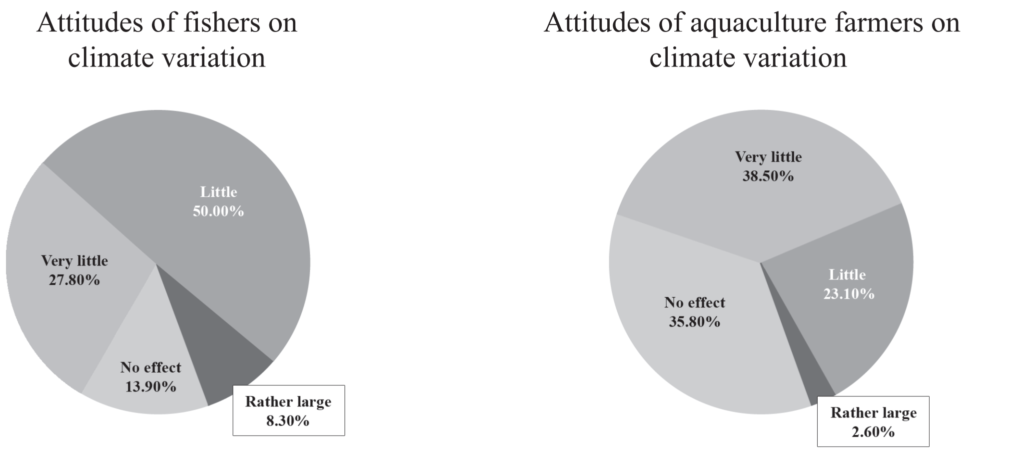

Figure 13. Attitudes of fishers and aquaculture farmers on the effects of climate variation on natural resources, the environment, and their livelihoods

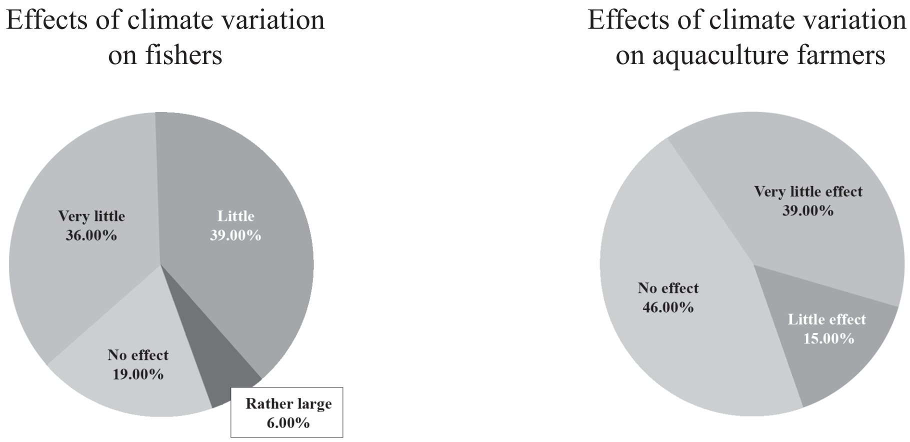

Figure 14. Effects of climate variation on fisheries and aquaculture livelihoods

CONCLUSION

Sea temperatures significantly affect the growth rate of mud crabs ($p < 0.005$), with crabs kept in 33°C water having the highest growth rate. However, this growth rate was not significantly different from that of crabs raised in 30°C water ($p > 0.05$). Crabs raised in 27°C water had the lowest average growth rate, gaining only 0.24 g per day. In addition, sea temperature also affected the density of phytoplankton over a period of 2, 3, 5 and 7 days ($p < 0.05$). The average density of phytoplankton was highest at 30°C. At this temperature, phytoplankton also had a higher growth rate and the least time required for the number of cells to double, when compared to other temperature treatments. However, if the sea temperature exceeded 32°C, the growth rate of phytoplankton decreased, affecting the growth of shellfish feeding on these organisms.

The effects of climate variation on the livelihoods of fishers would likely be a result of a shift in the rainy season, and an increase in the amount of rainfall. During the monsoon season, there may be an increase in the severity of waves and wind, and the timing of the season itself may shift. An increase in rain water would affect the amount of freshwater flowing into the sea and could reduce the resources available to marine organisms. Increased rainfall could also affect shellfish aquaculture due to a reduction in the salinity of culture areas, increasing mortalities and reducing the settling of shellfish spat.

Change in the timing of the monsoon season is another threat to the livelihoods of fishers and aquaculture farmers. Uncertainty regarding the timing of the monsoon season means that fishers are unable to safely determine when they can go out fishing, and that aquaculture farmers are unable to prepare their culture areas in time, resulting in a loss of shellfish production.

In order to deal with climate variation events and manage fishing and aquaculture activities, fishing communities should listen to news regarding the weather before making decisions. Besides that, they should exchange information on the weather and use warning systems within their communities. Additionally, the government should develop an effective method for forecasting weather, rainfall, and freshwater runoff and improved communication channels. These will help fishing communities to adapt their activities in response to the changing climates and thus maintain their livelihoods for the future.

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