Adaptiveness to Enhance the Sustainability of Freshwater-Aquaculture Farmers to the Environmental Changes

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ABSTRACT

Two alternative physical adaptations of freshwater-aquaculture farmers were observed along the upstream Bangpakong Watershed, Thailand. First was the modification of aquaculture types: (1) completely changing former species to others; (2) mixing freshwater prawn with current cultured species; (3) mixing fish with *L. vannamei*, and second was the direct reaction to environmental changes, including adding freshwater into cultured ponds to reduce temperature and dilute salt concentration; modifying pond-depth; aeration application; and reducing the amount of food or net covering on the water surface during flooding. Principal component analysis revealed that four key components (Options, Learning, Competitiveness, and Plan) reflected the perceived adaptive capacity of farmers to environmental changes. However, culture types have no significant effect on these four components. Farmers with an alternative source of income and practicing monoculture fish farming tend to have a greater ability to change occupation. Old age and more extended experience in aquaculture indicated a low ability to change occupation. The well-educated farmers and farmers who preferred to pass on aquaculture occupation to their children showed higher ability to learn and adapt, but this is not the case for older farmers. Thus, understanding the adaptations of the farmers may assist in promoting appropriate development programs based on their contexts as well as helping decision-makers to have a better plan for strengthening their adaptive capacities based on their perceptions.

1. INTRODUCTION

The frequency and severity of environmental changes may lead to uncertainty in aquaculture production (Handisyde et al., 2017; Lazard, 2017) and likely to a decline in freshwater-aquaculture production in Thailand (Department of Fishery, 2019). Over the past two decades, aquaculture production at the global scale and in Asia has shown an increasing trend (FAO, 2017), which indicates upward demand in the future. On the other hand, adaptation to environmental changes of aquaculture farmers as food producers could be another dimension of food security of concern that needs to be studied. Especially, important are freshwater farmers that play a role in stabilizing the food supply as the primary protein source of reasonable price that tends to be easily accessible. Most of the aquaculture production on the global scale tends to be concentrated in Asian countries (Dubey et al., 2017), especially China, India, and Southeast Asian countries, with their combined production projected to reach 93.6 million tons by 2030 (The World Bank, 2013).This may lead to uncertainty in sustainability and food security with regards to accessibility of protein sources. In addition, unusual average annual precipitation and temperature related to climate change has affected environmental conditions around Thai Bay. This includes the Bangpakong Watershed, which comprises Nakhon Nayok River and Prachinburi River as dominant freshwater zones, and the Bangpakong River, which

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serves as a brackish water zone. During the dry season (1st November to 30th April), salt intrusion spreads landward a long distance from the Bangpakong River to the freshwater areas in Nakhon Nayok and Prachinburi Rivers, resulting in salinity increasing over 0.5 ppt. Whereas, during the wet season (1st May to 31st October), a high amount of freshwater spread from Nakhon Nayok and Prachinburi Rivers to Bangpakong River results in salinity decreasing by around 0.5-5.0 ppt. Specifically, flooding is known to cause significant loss in shrimp production (Lebel et al., 2019; Seekao and Pharino, 2016a; Seekao and Pharino, 2016b). Thus, adaptation to environmental changes by freshwater-aquaculture farmers (called "farmers" in this paper) is increasingly becoming an important key for sustaining their livelihood, income generation, and food security in this sector. In this study, two forms of adaptation are described: physical adaptation and perceived adaptive capacity. The farmers were interviewed along the upstream of the Bangpakong Watershed (Nakhon Nayok province) where the salinity of the freshwater in the main river fluctuates periodically depending on the magnitude of saltwater intrusion (Srisurat, 2020). The farmers were hypothesized to have a variety of adaptations and likely have different perceptions on their adaptation capacities. Basically, these farmers, to some extent, have learned and adapted from time to time. For instance, they tend to preferentially culture Pacific White Shrimp (*Litopeneaus vannamei*) instead of *Penaeus monodon* due to its higher tolerance to diseases (Wyban, 2007) and high salinity from salt intrusion and may be a benefit derived for the farmers. Nevertheless, this shrimp species is still prone to many diseases during unfavorable conditions (Zhou et al., 2010; Han et al., 2018; Xu et al., 2021; Estrada-Cárdenas et al., 2021), causing farmers to change to other species or different aquatic fauna for culturing.

Most studies have focused on the physical adaptations of farmers, whereas few studies (e.g., Lebel et al., 2018) have focused on the perceived adaptive capacity of farmers. For instance, Lebel et al. (2018) revealed short-term reactions, seasonal tactics, and long-term adaptation strategies for fish farmers in northern Thailand in order to manage climate-related risks and market risks. Lebel et al. (2021) suggested that the perception of fish farmers against climate-related risks is also vital and indicated that wealthier and more educated farmers in the Mekong Basins tend to have better adaptive strategies for dealing with current risks. Thus, perceptions are a relatively strong factor that influences the motivation of farmers to adapt to environmental changes based on their history of understanding situations and experience in management practices. This study provides more insight into the adaptation and perceived adaptive capacity of the farmers in this area to cope with environmental changes and to maintain security of food production to meet the needs of the country. The objective of this study was to investigate farmers' adaptation (physical adaptation) and their perceived adaptive capacity (perspective of "how to adapt") against environmental changes due to saltwater intrusion, flood, drought, and fluctuation in temperature.

2. METHODOLOGY

Study participants were selected from households in four districts of Nakhon Nayok Province, located in central Thailand. The areas along Nakhon Nayok River were claimed as suitable for freshwater aquaculture, but marine intrusion was observed to affect these areas. Aquaculture activities observed around the study area consisted of monoculture of fish, monoculture of White-Leg Shrimp (*L. vannamei*), polyculture between *L. vannamei* and Freshwater Prawn (*Macrobrachium rosenbergii*), polyculture between fish and *L. vannamei* or *M. rosenbergii*, and polyculture fish (Figure 1). There are no complete lists of names and addresses of farmers in the study areas. Hence, snowball sampling and purposive representative sampling were applied from one farm to other farms with a minimum of 30 cases of each culture type existing in the study areas (i.e., monoculture of *L. vannamei*, monoculture fish, polyculture fish, polyculture between *L. vannamei* and *M. rosenbergii*, and polyculture between fish and *L. vannamei*) (Pollnac and Crawford, 2000). We sampled a total of 206 cases, which were statistically sufficient to represent a surrogate of farmers in the study sites. Face-to-face interviews were conducted from March 2017 to January 2018, using a semi-structured questionnaire approved by the Central Institutional Review Board of Mahidol University.

2.1 Dependent variables, independent variables, and data analysis

Adaptation was measured in two forms: (1) physical adaptation was observed and farmers were interviewed with open end questions on how frequently they adapt to changes or stresses using descriptive explanations that directed reactions to environmental stresses including salinity change, drought, flood, and fluctuation in water temperature; (2) perceived adaptive capacity on the changes: farmers were asked to indicate their level of agreement with 12 variables (Supplementary data) modified from Marshall and Marshall (2007). A 4-level Likert scale ranging from strongly disagree to strongly agree was applied to measure these variables. This study used the same scales suggested by Marshall and Marshall (2007). In this case, a mid-point was not comparable after data analysis.

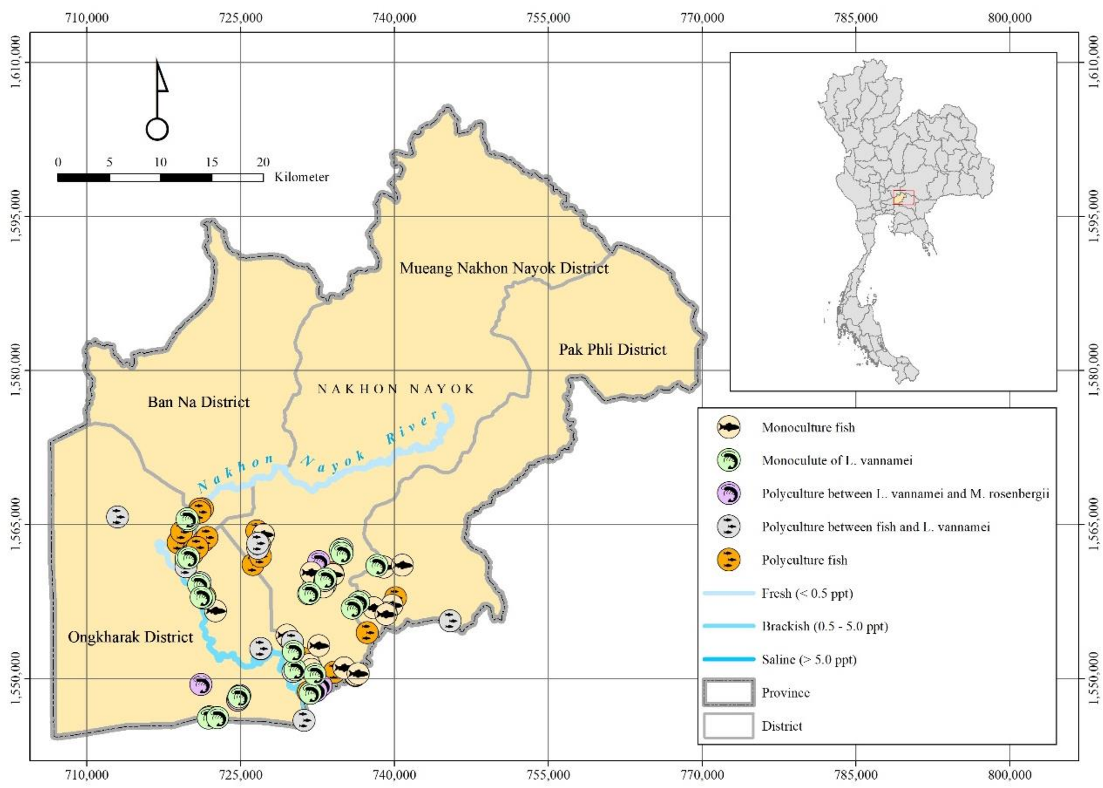

Figure 1. Distribution of existing aquaculture activities around Nakhon Nayok Province

Another set of questions was used to gather demographic information (i.e., age, education, aquaculture experience, household size, gender, religion, number of kin involved in aquaculture, marital status, aquaculture ownership, type of aquaculture, official registration, income from aquaculture, satisfaction with income, climate change awareness, and job satisfaction). These were variables related to perceived adaptive capacity.

Descriptive results on physical adaptation of farmers were provided with regard to the classification of aquaculture types and the grouping of environmental stresses. The perceived adaptive capacity was analyzed using Principal Component Analysis (PCA). The relationship between dependent and independent variables was analyzed using Pearson's correlation (Freedman et al., 2007) and Student's t-test (Kalpić et al., 2011). Statistical software, SPSS version18 was used for the analysis.

3. RESULTS AND DISCUSSION

3.1 Demographic results

Based on a total of 206 respondents, the male: female ratio was close to 1:1 (56.8% male). Most respondents were married (91.7%). The average age and education level was 53.3±12.9 and 6.9±4.1 years, respectively. Households had an average of four members. Respondents had an average of 13.9±8.5 year-experiences in aquaculture. On average, one person in each household assisted in aquaculture. Most of them (81.6%) shared that they have relatives engaged in aquaculture. About 60.7% of respondents depended on income not only from aquaculture but also other jobs such as farming, employment, trading, and raising animals.

When asked for opinions on income, it was found that most respondents earned enough income to cover their family's food expenses (51.9%), family expenses (50.4%), children education (52.4%), and

36.4% had insufficient income to save for future necessities. Respondents said they had uncertain income in each production cycle. For instance, making profits in some years, and losses in other years. Thus, they do not have enough money to save. In addition, some had debts from the mega-flood disasters in 2011 and 2013 that resulted in huge losses of aquaculture profits. Concerning the opinions on job satisfaction, most farmers (94.7%) were satisfied with aquaculture and willing to continue it in the future. About 53.4% of respondents agreed with recommending their children to pursue working in aquaculture because they already have land and they have experience to pass on, while 27.7% said they do not want their children to work in aquaculture, because it is a difficult and high-risk career. They wanted their children to have a good education and pursue other occupations to gain more stable income. About 18.9% did not know whether they should or should not recommend their children to do aquaculture.

3.2 Physical adaptation to environmental stresses

The majority of respondents owned farms (94.7%) and were observed having two alternatives of physical adaptation: (1) three modifications of aquaculture type, and (2) direct reaction to environmental changes (salt intrusion, drought, flood, and water temperature change).

The three modification of aquaculture type for adaptation were classified as

(A) Modification by completely changing the former species to others: The complete conversion from monoculture of *L. vannamei* to polyculture fish was mentioned, which has higher resistance to diseases and environmental changes. Polyculture fish reduces the risk of diseases through feeding behaviors of different kinds of species throughout the aquaculture system. Waste elimination leads to the better water quality and environmental conditions resulting in preventing diseases. The polyculture fish was observed for 37.9% of the farmers, while monoculture *L. vannamei* was observed for 24.3% of the farmers. Nevertheless, the observed 37.9% does not represent all of the farms converted from monoculture of *L. vannamei*.

(B) Modification by mixing Freshwater Prawn (*M. rosenbergii*) with former cultured species: The polyculture between *M. rosenbergii* and *L. vannamei* was observed for 18% of the aquaculture farms. Among these farms there were some that had converted from monoculture *L. vannamei*. In this case, farmers tend to have less risk of potential loss of entire profits by selling *M. rosenbergii* in situations where there is loss in yield of *L. vannamei* owing to adverse environmental impact. In addition, polyculture between *L. vannamei* and *M. rosenbergii* resulted in higher yield compared to a monoculture of *L. vannamei*, which seems consistent with that reported by Chuchird et al. (2009) for Ratchaburi Province.

(C) Modification by mixing fish with *L. vannamei*: The culture mixing between polyculture fish and *L. vannamei* was observed in 20.4% of the farms. In this modification type, farmers did not want to mention the former species they cultured before conversion. Probably, the farmers were suspicious about the rationale behind the question, and thus unwilling to share the details of the previously cultured species. Farmers can harvest *L. vannamei* 2-3 times per one harvest of the polyculture fish, providing them with additional income. This observation is in line with Dailynews (2015) for polyculture between Tilapia and *L. vannamei* in Chonburi Province where the farmers harvested *L. vannamei* every 2-3 months during 10 months of Tilapia culturing and earned income higher than usual (the price of *L. vannamei* was 250 Baht/ kg vs. Tilapia 35-40 Baht/kg in 2015).

Other culture types which do not fall into the three modification types mentioned above were also observed. These other farms had various monoculture fish (i.e., Fry Catfish 12.1%; Red Tilapia 5.8%, Catfish 3.4%, Tilapia 3.4%, Snapper 1%, and others 0.5%) that were not related to adaptation strategies in this area.

Among these three types of modification around 59.2% were semi-intensive, including polyculture fish, polyculture fish with *L. vannamei*, and monoculture of Fry Catfish. Approximately 40.3% were intensive; monoculture of *L. vannamei*, polyculture between *L. vannamei* and *M. rosenbergii*, and Red Tilapia fish cages. A minority of farmers (0.5%) applied extensive culture.

In terms of direct response to the environmental changes, respondents revealed adjustment of environmental conditions when facing undesirable stresses (salt intrusion, drought, flood, high and low water temperature) in several ways. A common method applied against environmental stresses was adding freshwater into the ponds but not in the case of low water temperature. Aeration increase was also commonly applied against flooding and temperature changes. Details of adaptations are as follows.

During periods of salt intrusion, salinity in the ponds also increased through pipelines or outlets. All types of aquacultures would pump freshwater into the culture ponds. For the *L. vannamei* culture, farmers pumped saltwater out of the ponds then diluted the salt concentration in the ponds with freshwater and controlled the salinity to not exceed 10 ppt. In some cases, farmers would change from culturing *L. vannamei* to Sea Bass fish during the period of high salinity in the river and later change back to the former culture type. The results were in line with De Silva and Soto (2009) who reported that farmers have an adaptive strategy during salt intrusion by shifted stenohaline species to euryhaline species to reduce costs, and Cruz (2016) who reported that a mono-sex Tilapia fish was an alternative to culture of Tiger shrimps during unfavorable conditions.

For the drought condition, the first mechanism for response in all aquaculture types was the pumping of freshwater from storage ponds into culture ponds. Read (2007) and De Silva and Soto (2009) also suggested that rainwater storage, dry-plant covering on water surface, regular maintenance of a pond structure, and keeping deeper pond depths can help prevent the loss in aquaculture production during drought conditions. However, this is different from the culture of Fry Catfish and Red Tilapia in cages, which in this study, farmers tended to temporarily stop culturing due to unsuitable water content consistent with the findings of Flaherty et al. (1999).

During flooding, all aquaculture types use nets to cover the ponds and increase the pond dikes to prevent aquatic animals from slipping into the flooded water similar to that observed by other studies (Shameem et al., 2015; Seekao and Pharino, 2016a; Seekao and Pharino, 2016b), whereas covering discharge pipe outlets with a net was applied with the culture of Giant Catfish (Teongphukeao, 2012). Some farms may harvest before the planned schedule (Shameem et al., 2015). In addition, running water could have been changed temporarily to stagnant water during flooding that caused low oxygen. Thus, increasing aeration would be applied. Those who cannot afford any prevention would have changed species or culture methods after flooding (Nguyen et al., 2015). Aside from the flooding, storm surge in some areas can adversely affect water quality in the culture ponds (Ahmed and Diana, 2015) and raise water levels higher than usual, so almost the same techniques used during flooding are also applied.

Water temperature change, both high and low degrees affected adaptation of farmers differently. All aquaculture types pumped freshwater from storage ponds into culture ponds when water temperature increased, but not during the low temperature. Instead, they reduce the amount of food and feeding time during cold conditions due to the low rate of shrimp metabolism and to prevent anoxia conditions caused by food waste at the bottom of the ponds. These adaptations were different from a reported common technique elsewhere which is to modify the depth of a pond to be deeper than usual, especially in shrimp farms (Shameem et al., 2015). In our studies, farmers would increase aeration during both high and low temperatures for the culture type of monoculture *L. vannamei*, and polyculture between *L. vannamei* and *M. rosenbergii* that can reduce the heat and prevent stratification of water temperature. In other studies, farmers adopt the higher tolerant species instead of providing aeration (De Silva and Soto, 2009). Another adaptation technique observed in our studies to reduce the heat was to pave straws in the ponds on the water surface.

3.3 The perception and perceived adaptive capacity to environmental changes

Most farmers (93.7% of total respondents) were aware of climate change and perceived that, over the past 10 years, climate change may have had an impact and threatened aquaculture production through several changes. However, farmers' perception on the stresses that most affect aquaculture production were salinity increase (55.3%), drought (54.9%), and flood (51.5%), respectively. This was followed by increasing water temperature in the hot season (44.7%), decreasing water temperature in the winter season (40.3%), water pollution (23.3%), first rainfall (22.2%), water acidification (19.9%), increasing rainfall (10.7%), climate variability (6.3%), and air pollution (5.8%), respectively.

The PCA with varimax rotation of the 12 variables resulted in four components, explaining 65.74% of the variance in the dataset (Table 1). The components were named "Options" (opportunities and confidence to get work elsewhere), "Learning" (change work, cope with small changes, more likely to adapt, and learn new skills), "Competitiveness" (can survive more changes, things will turn out well) and "Plan" (plan for finance security and competitive), based on the content of variables loading highest on the component, a common practice associated with the use of this technique. The "Options" component explained 24.46% of the variance in the dataset, followed by "Learning", "Competiveness", and "Plan" (18.82%, 12.82% and 10.24%, respectively) (Table 1). These four components were used as indicators of farmers perceived adaptive capacity to deal with the future changes. In this study, the "Plan" component explained the least variance in perceived adaptive capacity of farmers. However, the higher the plan perception, the better planned farming that contributes to improve *L. vannamei* farmers' benefits in the south and east of Thailand (Sanrak, 2010). For instance, using good quality breeders as one of the farming plans could be one alternative of the adaptation methods (Boonstra and Hanh, 2015).

Table 1. Components as indicators illustrate perceived adaptive capacity of the farmers

Items	Components			
	Options	Learning	Competitiveness	Plan
Confident to get work elsewhere	**0.888**	0.203	0.139	0.100
Many options available	**0.852**	-0.062	0.034	0.008
Not nervous trying something else	**0.820**	0.167	0.089	0.018
Not too old to find work elsewhere	**0.748**	0.386	0.087	0.098
Plan to make change work for me	-0.005	**0.779**	0.227	0.068
Can cope with small changes	0.170	**0.719**	0.039	0.108
More likely to adapt to change than others	-0.072	**0.624**	0.173	0.307
Interested in learning new skill	0.303	**0.554**	-0.063	-0.093
If more changes will survive	0.222	-0.011	**0.868**	0.077
Confident things will turn out well	0.031	0.302	**0.813**	-0.069
Planned for financial security	0.111	-0.039	-0.008	**0.799**
Competitive enough to survive much longer	0.019	0.306	0.012	**0.664**
Percent total variance	24.46**%**	18.22%	12.82%	10.24%

3.4 Factors influencing perceived adaptive capacity

Demographic information on farmers age, years of aquaculture experiences, and education level averaged 53.3±12.9, 13.9±8.5, and 6.9±4.1 years, respectively. These are the three main variables that tend to affect farmers perceived adaptive capacity and seem to be consistent with other studies (Satumanatpan and Pollnac, 2020; Satumanatpan and Pollnac 2017). The older adults have lower ability to work ($r=-0.249$, $p<0.01$) and learn ($r=-0.222$, $p<0.01$) compared to the younger ones. In addition, the results indicate that farmers engaged in aquaculture for a longer period of time tend to have significantly less adaptation with regards to other forms of occupation ($r=-0.157$, $p<0.05$). Gender (more males than females), marital status (most married 91.7%), and family members engaged in aquaculture (averaged four per household) appear to have no significant influence on perceived adaptive capacity of farmers.

Farmers with higher education level had the ability to learn and adjust better than those with lower education ($r=0.299$, $p<0.01$) implying higher perceived adaptive capacity. This seems to be in line with Rattanadechakorn (2012) who suggested that local fishermen who have higher indigenous wisdom may have better adaptive strategies of survive and thus, tend to lower their vulnerability to seasonal alteration in climatic conditions. In addition, the good knowledge on environmental changes may enhance perceived adaptive capacity. This could be explained with the study of Sanrak (2010) who suggested that farmers of *L. vannamei* in southern and eastern Thailand tend to have higher production and earn more profits through sharing of knowledge and experience.

Aquaculture types have no significant effect on the four components of the perceived adaptive capacity (Table 2) that were compared between monoculture of *L. vannamei* vs monoculture fish (Part B1), monoculture *L. vannamei* vs polyculture between *L. vannamei* and *M. rosenbergii* (Part B3), polyculture fish vs polyculture fish with *L. vannamei* (Part B4). However, an indication of small effect (effect size=0.028) revealed that the monoculture fish perceived higher ability on work options than the polyculture fish (Table 2 part B2, $t=1.997$, $p<0.05$).

Farmers who earned income only from aquaculture (39.3%) have significantly lower flexibility in work options than those having income from both aquaculture and other occupations (Table 2 Part A, t=-3.883, p<0.01). Diverse alternative incomes were also reported as one significant adaptation option of rice and fish farming households in Vietnam (Tri et al., 2019), and for small-scale fishermen in Thailand (Satumanatpan and Pollnac, 2020; Satumanatpan and Pollnac, 2017; Tongpli, 2011).

Analysis of aquaculture satisfaction towards adaptation (Table 2 Part C), indicates significantly higher ability to learn and adapt (*Learning* component) among those who prefer their children to continue aquaculture (effect size=0.073, t=3.265, p<0.05). Probably, their perceived adaptive learning could help them overcome any problems and enable their children to also learn how to adapt. Moreover, most of them already owned well equipped farms, thus they likely felt learning and adaptation could be an easy task. In contrast, those who did not advise their children to continue aquaculture, raised concerns that they were unable to cope with environmental stresses and felt difficulties with their own jobs, i.e., working hard, risky, and uncertain income. In this respect, the *Learning*-perceived adaptive capacity of the farmers seems to be in line with Lebel et al. (2021) who suggested that wealthier and more educated farmers could better deal with current risks related to climate change as well as recognizing the need for adaptation strategies for future changes in climate. Finally, official registration as being freshwater-aquaculture farmers with the fishery provincial office did not influence the level of perceived adaptive capacity. Farmers indicated that they did not receive assistance when they encountered stress.

Table 2. The t-test analysis between independent and dependent variables

Part	Independent variables	Values	Dependent variables			
			Options	Learning	Competitiveness	Plan
A	Income aquaculture vs income aquaculture +	t	-3.883	1.651	-1.025	-1.661
	others	P	0.000**	0.100	0.307	0.098
B1	Monoculture of *L.vannamei* vs Monoculture fish	t	-0.455	0.239	1.488	-0.109
		P	0.649	0.811	0.138	0.913
B2	Monoculture fish vs Polyculture fish	t	1.997	0.144	0.539	0.668
		P	0.048*	0.886	0.591	0.506
B3	Monoculture *L.vannamei* vs Polyculture of	t	-1.253	0.336	-0.832	1.579
	L.vannamei and *M. rosenbergii*	P	0.214	0.738	0.408	0.119
B4	Polyculture fish vs Polyculture fish	t	1.004	-0.965	-1.293	-0.195
	with *L. vannamei*	P	0.318	0.337	0.199	0.846
C	Advise vs Not advise to do aquaculture	t	-1.560	3.265	-0.309	0.244
		P	0.121	0.001*	0.758	0.807
D	Registered vs Non-register	t	-0.244	-0.701	0.621	-0.116
		P	0.808	0.484	0.535	0.908

*p<0.05, **p<0.01; Effect size: small=0.01, moderate=0.06, large=0.14;
A (n=81:125), B1 (n=69:137), B2 (n=44:93), B3 (n=38:31), B4 (n=57:36), C (n=110:57), D (n=174:32)

4. CONCLUSION

The study indicates that farmers in Nakhon Nayok Province tends to show different adaptive capacity to environmental changes depending on species-reared, environmental stresses, and their perception. Salt intrusion in the freshwater zone of Nakhon Nayok River appears not to be a major problem for the farmers to modify their aquaculture activities and sustain their livelihoods. However, the marketing mechanism and severe change in environmental conditions drive the farmers to adapt from time to time, which has become natural habits expressed through their physical reactions either by culturing modifications or reacting directly to the specific stresses.

Our findings suggest that understanding adaptations of the farmers should not only be restricted to physical adaptation, but also perceived adaptive capacity which is in part significant to designing aquaculture-development programs. Based on the preference of most respondents, supplemental sources of income are recommended to help farmers sustain their aquaculture practice. In this respect, complete change of job skills is not recommended, instead, farmers should be trained for upskills, for instance, in polyculture and advanced technology application.

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