SEAMEO SEARCA 50 1966-2016

SEARCA Agriculture & Development
Discussion Paper Series
No. 2016-3

# Impact of Climate Change on Aquaculture in Phu Vang District, Thua Thien Hue Province, Vietnam

Mac Nhu Binh
Le Van An
Nguyen Thi Thanh Thuy
Ngo Thi Huong Giang
Ho Thi Thu Hoai
Truong Van Dan

SOUTHEAST ASIAN REGIONAL CENTER
FOR GRADUATE STUDY AND RESEARCH IN AGRICULTURE

Science and education for agriculture and development
www.searca.org

**SEARCA**
Agriculture & Development
Discussion Paper Series

No. 2016-3

# Impact of Climate Change on Aquaculture in Phu Vang District, Thua Thien Hue Province, Vietnam

**Mac Nhu Binh**
**Le Van An**
**Nguyen Thi Thanh Thuy**
**Ngo Thi Huong Giang**
**Ho Thi Thu Hoai**
**Truong Van Dan**

**SOUTHEAST ASIAN REGIONAL CENTER FOR GRADUATE STUDY AND RESEARCH IN AGRICULTURE**
*Science and education for agriculture and development*

**Mac Nhu Binh**
Hue University of Agriculture and Forestry
102 Phung Hung Street, Hue City, Vietnam
macnhubinh@huaf.edu.vn
nhubinh2510@gmail.com

The **SEARCA Agriculture and Development Discussion Paper Series** aims to disseminate information on current trends or researches to inspire discussion between the author and other stakeholders in the same field of interest. SEARCA encourages readers to directly contact the author through the address provided or join the discussion board for this paper at http://bit.ly/searca-dps-2016-3.



This publication was peer-reviewed.

# ABSTRACT

Climate change is a major global concern that greatly affects people, including their source of living. In 2010, the Asian Development Bank reported that Vietnam is one of the five countries most severely affected by climate change. About 70 percent of the country's total population lives along coastal areas and in islands. This study aimed to (1) evaluate the impacts of climate change on aquaculture in Phu Vang district (Thua Thien Hue province, Vietnam), and (2) develop a climate change adaptation model for aquaculture. Data on impact of climate change to aquaculture production were gathered through participatory rural appraisal tools, while spatial changes in water quality were determined through Geographic Information System (GIS). Experimental polyculture models were set up in the five study-site communes to determine the aquaculture practices that could be disseminated to small farmers. It was found out that Phu Vang had suffered heavy losses from climate change brought about by a combination of droughts and prolonged heat waves, and cold weather that lasted longer. Floods and typhoons have likewise occurred with stronger intensities, and tide amplitude has changed drastically. All these affected agricultural activities, especially aquaculture, which is considered as one of the most vulnerable sectors to climate change impacts. As a result, many households shifted from intensive to extensive culture, and some even left their ponds for other jobs. The limited understanding and capacity of people on climate change aggravated the situation, affecting their ability to respond and mitigate negative impacts. Water quality, specifically for aquaculture, was also affected as a result of rising temperature, prolonged droughts, rainfall, flooding, and salinization, which in turn reduced productivity and yield. Meanwhile, polyculture models of aquaculture implemented for this study brought high economic returns, and could be promising to replicate in various communes of Phu Vang district. The following are the primary recommendations to mitigate climate change impact in aquaculture and to facilitate sustainable livelihood for coastal people: capacitate communities and government in climate change adaptation and mitigation; expand promising aquaculture practices, area, infrastructure, and marketing of produce; and implement policies to mitigate damages of climate change to aquaculture and the community as a whole.

# INTRODUCTION

### Rationale

The world faces a host of environmental problems, ranging from climate change to loss of biodiversity, depletion of fresh water resources, thinning of the ozone layer, land degradation, desertification, and the like. All of these phenomena that interact together directly affect human lives.

Vietnam's vulnerability to natural disasters and to climate change comes from an interplay of climatic and geographic factors. The country has around 3,260 kilometers (km) of coastline and over 3,000 islands, where more than 70 percent of its population live. The rural low-lying coastal areas, especially those in the central region provinces of Quang Binh, Quang Tri, Thua Thien Hue, Da Nang, and Quang Nam are highly vulnerable to water-related natural disasters and sea-level rise.

As a coastal province in the center of Vietnam, Thua Thien Hue has 128 km of coastline, 22,000 hectares (ha) of lagoon (Tam Giang-Cau Hai lagoon), and more than 200,000 ha of forest (Suu and Binh 2006). More than 380,000 inhabitants live around and in buffer zones of the 70-km Tam Giang-Cau Hai lagoon along the coastal region, traversing north to south of Thua Thien Hue (Binh et al. 2010). The province has a total population of 1,090,879, and those living around the lagoon system constitutes 32 communities in 5 districts and in 236 villages. They earn their living by directly or indirectly exploiting the natural resources in and around the lagoon (Tuong et al. 2008). Their common livelihood activities include fishing, aquaculture, and farming. Aquaculture systems are diversified, consisting mainly of ponds and net enclosures under high and low tides. As aquaculture is a major component of the economy of Thua Thien Hue, its development is regarded as top priority.

Phu Vang district is bounded in the east by the East Vietnam Sea, in the west by Huong Tra district and Hue City, in the north by Quang Dien district, and in the south by Phu Loc district. The Phu Vang lowlands has a total land area of 28,032 ha, of which 10,829 ha is agricultural land; 13,933 ha is non-agricultural; and 3,269 ha is idle land. The district is inhabited by 182,336 people at a population density of 647 per square kilometer ($km^2$) and a work force of 85,830 (Phu Vang district 2013).

The communities in Phu Vang district generally depend on three main income-generating activities: open fisheries, aquaculture, and livestock. Other complementary occupations include trading, seasonal work, construction, and services. Considering that aquaculture and open fishing remain as the primary sources of income and main driver of the local economy, disaster events and the potential effects of climate change pose huge challenge to Phu Vang district (Suu et al. 2010). This has been confirmed in this study through stakeholder consultations using participatory rural appraisal, including surveys. Many types of disasters and climate change impacts had been witnessed in the district, similar to experiences of other coastal and lagoon areas of Thua Thien Hue province.

The local people see floods and storm events as the greatest threats because these can trigger sudden and strong change of sand bars and lagoon basement, otherwise known as lagoon-gate-opening effect. One such phenomenon occured in Hoa Duan commune in 1999, wherein 64 households were washed-out and hundreds of people died (Trap 2006). In addition, coastal hydrodynamic changes can lead to the destruction of important infrastructures such as dikes and houses. Very deep erosion of up to hundreds of meters may be seen in one place and heavy sedimentation in another. Drought is another extreme condition that affects aquaculture activities in the locality. Furthermore, environmental pollution and disease outbreaks have, in recent years, greatly affected the productivity of aquaculture, particularly shrimp culture in Phu Vang.

Studies that assessed climate change impacts on agricultural production in Vietnam, specifically in Thua Thien Hue, have shown negative impacts. Since 2007, water pollution and water shortage have also been found to reduce productivity of aquaculture (FAO 2012) although these studies were not focused in Phu Vang district. Notwithstanding, appropriate measures are yet to be introduced to mitigate the effects of climate change and ensure the sustainability of aquaculture in the locality.

### Objectives of the Study

This study aimed to evaluate the impact of climate change on aquaculture in Phu Vang district, Thua Thien Hue province, Vietnam, and to develop an aquaculture model that adapts to such climate effects. Specifically, the study was designed to:

1. describe and analyze the natural and socio-economic conditions of Phu Vang district;
2. evaluate the impacts of climate change on water quality, aquaculture productivity, and social activities;

3. develop a climate change adaptation model for aquaculture based on biophysical conditions of ponds and management practices of aquaculture producers; and
4. document and evaluate good aquaculture models and provide recommendations to local stakeholders on issues related to mitigating the effects of climate change on aquaculture.

## Background

### *Climate in Thua Thien Hue province*

Thua Thien Hue is generally located in the tropical latitude region, the transition from northern to southern climate area. Its climate is affected by the western and southern mountain ranges, which during winter, influence the northeast wind, changing its direction to the northwest. The cold air mass stays in the east of the Truong Son Range and North Hai Van Pass, causing heavy rain and flooding by the end of autumn nearing winter (ADB 2010). This situation creates one of the biggest rainfall centers in the entire country. In summer, the mountain ranges cause the "fern" effect, leading to extremely dry and hot weather accompanied by drought. The diverse topography of Thua Thien Hue also causes the differentiated climate that creates many subclimatic areas. Every year, climatic conditions tend to be increasingly severe. Typhoons, heat waves, droughts, and floods result in socio-economic losses (Thanh 2011).

Using long-term data, the annual number of typhoons that hit Binh Tri Thien (administrative grouping of the provinces of Quang Binh, Quang Tri, and Thua Thien Hue) ranges from 3 to 10, occurring from May to November, but mostly in September and October (Table 1). According to Suu and Binh (2006), the 120-km-long coastline of Thua Thien Hue has a very complicated tide profile. From South Quang Tri (at the northern tip of Thua Thien Hue) to Thuan An Estuary (within Phu Vang district), the tidal regime is irregularly semi-diurnal almost all days in a month, with average magnitude of 1.2–1.6 meters (m), decreasing as it goes south. The coastal area neighboring Thuan An Estuary has

**Table 1. Average number of typhoons in Binh Tri Thien (Quang Binh, Quang Tri, and Thua Thien Hue provinces)**

| | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|
| Typhoons (no.) | 3 | 4 | 3 | 4 | 10 | 8 | 3 | 35 |
| Proportion (%) | 9 | 11 | 9 | 11 | 29 | 22 | 9 | 100 |

Source: Tuong et al. (2010)

a regular semi-diurnal regime each day as the tide goes up and down twice. Tide fluctuation here is the smallest. The daily amplitude of the water at Thuan An Estuary is about 30–50 centimeters (cm); it is bigger in the Tu Hien area at about 55–100 cm. In the southern area, the tide changes into diurnal (20–25 days of diurnal tide/month; fluctuation amplitude in springtide is 80 cm). At the Chan May area, average amplitude is 70 cm, maximum value is 145 cm, and minimum is 20 cm. Here, average tide level is 0.87 cm with maximum of 126 cm and minimum of –72 cm.

The wave regime is affected by the monsoon. In the coastal area on winter time, waves in the north and northeast directions prevail. In Thuan An Estuary, the wave in the northeast direction has frequency of 99 percent and height of 0.25–3 m. The wave direction in the open seas in summertime is mainly southwest and southeast; it is southeast in the coastal area. In Thuan An, the wave in the east direction is 0.2–1.0 m high with frequency of 99 percent. Suu et al. (2010) mentioned that Thua Thien Hue had experienced climatic fluctuations in the past, many of them affecting the local socio-economic situation. Changes in power resources and more intense and complex weather-related phenomena have affected the livelihood of local residents, despite several infrastructure projects and policy frameworks to develop the local economy.

### *Phu Vang district*

Phu Vang is a coastal district downstream of Huong River that has a diversity of landscapes. It has low-lying agricultural land mixed with aquaculture ponds covering the river estuary. It forms part of the Tam Giang-Cau Hai lagoon. As one of the most vulnerable districts in Thua Thien Hue province, it faces constant threat from both the ocean—with typhoons, storms, sea level rise, and saline intrusion—and the river with floods and droughts. Low awareness level and very limited sources of income among local people, along with their unwillingness or inability to resettle, contribute to the huge loss of human lives and property when natural disasters strike.

Since ancient times, Phu Vang district and the Huong River basin have many times been affected by numerous typhoons, storms, floods, droughts, and landslides. Tuong et al. (2008) also mentioned that in recent years, such disasters have increased in both frequency and intensity, causing significant socio-economic turbulence and loss of life, seriously damaging upstream and downstream infrastructure and ecology, thus, destroying people's livelihoods and property.

Research has predicted that the flooded area in Phu Vang is likely to become more extensive because of climate change. It was found out that the effects of a November 1999 catastrophe, when 36.4 percent of the area was flooded, can potentially reach 40.4 percent of the area if a similar event were to occur in the future (Trap 2006). Drought and salinity intrusion are also expected to increase based on the same climate change scenario. By the end of the century, salinity in the mouth of Huong River could increase by 20–40 percent. Saline intrusion may penetrate 2–3 km farther upstream than at present, if proper countermeasures were not undertaken.

Aquaculture in Thua Thien Hue province has been heavily affected by climate change in recent years (Binh, Chat, and Thuy 2010). Yield was reduced from 40 to 50 percent in 2011. Some regions such as Phu Vang and Quang Dien districts did not engage in shrimp culture for almost five years (2007–2011) because of water pollution and climate change effects. An and Hoang (2007) concluded that climate change will have a great impact on Thua Thien Hue, as it is part of the Tam Giang and Cau Hai lagoon system. Significant changes in temperature and annual rainfall are expected. Flood frequency will also be higher than that observed in the last 10 years. Flood incidence is projected to increase up to Year 2100 (Table 2). The loss of forest vegetation in the upland areas of Thua Thien Hue province is one of the factors that adversely affect aquaculture production in some coastal communities. Further studies on climate change are therefore needed to develop sustainable aquaculture in these areas.

### *The project area*

In 2011, Phu Vang district had a population of 178,968 residing in a 280-km² area. It covers 20 communes, namely: Phu Tan, Thuan An, Phu Da, Phu Xuan, Phu Mau, Phu Thanh, Phu My, Phu An, Phu Ho, Phu Duong, Phu Thuong, Phu Hai, Phu Thuan, Phu Dien, Phu Luong, Vinh Xuan, Vinh Thanh, Vinh An, Vinh Phu, Vinh Thai, and Vinh Ha (see Figure 1). Thuan An town in Phu Vang district is located on the depressed estuary plain of the Huong River basin. Part of the lagoon area is occupied by residents of Thuan An villages; another seven are near Tam Giang-Cau Hai lagoon, and five are close to the sea (Tuong et al. 2008).

**Table 2. Projected flooding scenarios in Phu Vang district**

| | 1999 | 2030 | 2050 | 2070 | 2090 | 2100 |
|---|---|---|---|---|---|---|
| Depth of flood (m) | 5.8 | 5.96 | 6.08 | 6.16 | 6.27 | 6.44 |
| Area of flood ($m^2$) | 102.1 | 105.8 | 109.4 | 111.2 | 113.0 | 114.4 |
| Proportion of flooded area (%) | 36.4 | 37.2 | 39.0 | 39.2 | 40.3 | 40.8 |

Source: An and Hoang (2007)

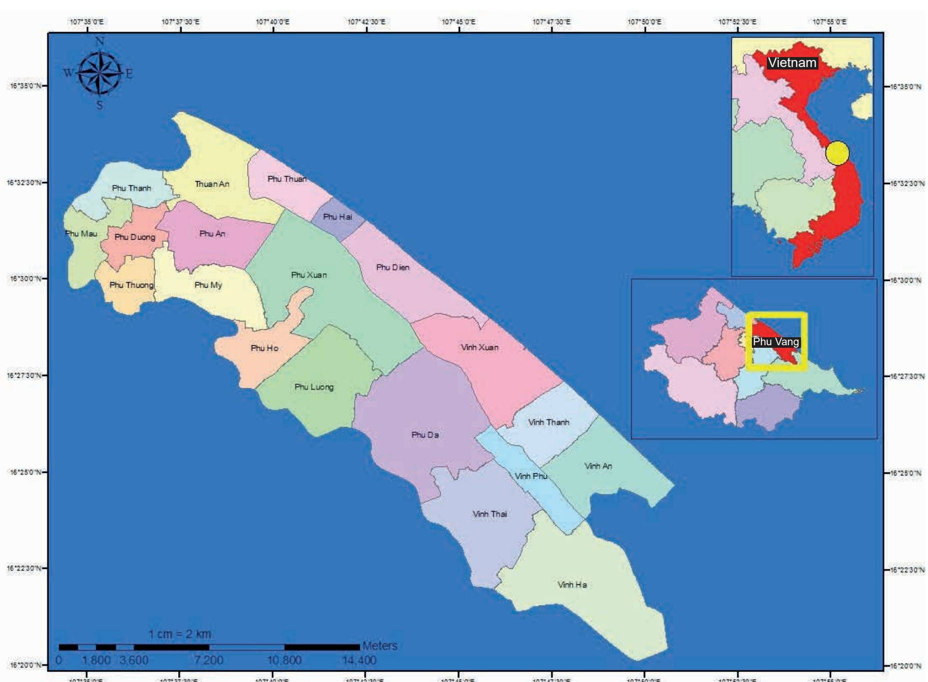
# METHODOLOGY

### Research Design

The study focused on five coastal communes that engaged in aquaculture production, namely: Thuan An, Phu Thuan, Phu Hai, Phu Duyen, and Phu Tan (Figure 1). General information on weather and climate conditions and current environmental situation related to water quality and aquaculture in Phu Vang district were collected.

To evaluate the impact of climate change on aquacultural production and the whole society of Phu Vang, secondary and primary data were gathered from multiple sources. Secondary data were obtained from government agencies including the Department of Fisheries, the Department of Environment and Resources, and the district agricultural office. Data from 1975 (TTHSO 2012) up to the present were analyzed. Some factors affected by climate change and that

**Figure 1. Map of Phu Vang district showing the study sites**



would have impacts on aquaculture activities in the locality were determined and assessed, e.g., land use for aquaculture, sea level rise, ambient temperature increases, water resources, environmental pollution, droughts, and floods.

### *Participatory rural appraisal*

Participatory rural appraisal (PRA) was conducted to collect vital information from the communities, and to place people at the center of the research process. The appraisal tools—e.g., stakeholder analysis, key informant interviews, and focus group discussions—were used to encourage the participation of local people. Experiences, opinions, knowledge, and adaptation measures to climate change were identified using this method.

The information collected and analyzed included those pertaining to the socio-economic situation of the community, the historical changes of weather-related phenomena, people's awareness of their impacts, and the community's response to them. Depending on each tool, different groups of people were invited to take part in the activities. To get an overview of the locality, a historical profile and a mobility map were constructed with the assistance of village officials and the elderly. Equal participation of women, men, and the youth was encouraged.

### *Focus group discussion*

Focus group discussions enabled participants to elaborate on topics related to climate change, their impacts, and what adaptation measures relative to aquaculture activities may be implemented.

### *Surveys*

Questionnaires were developed for data collection. Fisherfolks (directly or indirectly involved in aquaculture) who are members of families living in the research area were targeted as respondents. A total of 203 respondents were randomly selected for this study. The survey aimed to verify the information collected during the PRA and to provide quantitative results.

Results were collated, synthesized, and analyzed to identify constraints and to come up with sustainable aquaculture strategies and climate mitigation measures for adoption in Phu Vang.

### *Geographic Information System*

Geographic Information System (GIS) was applied in water quality assessment using interpolation to determine spatial changes in water quality in the study sites.

### *Water quality assessment*

The quality of water was assessed by comparing environmental parameters with standards set in the National Technical Regulation on Coastal Water Quality (NTR 08/2008/MARD) (MNRE 2008) for aquaculture purposes and the National Technical Regulation on Surface Water Quality to Protect Aquatic Life and Water Quality Requirements for Aquaculture (Circular No. 44/2010/TT-BNNPTNT 2010).

### *Aquaculture models*

With the goal of developing good aquaculture practices for dissemination to small farmers in the locality in order to diversify their income sources, experimental polyculture model was set up in each of the five communes (i.e., Thuan An, Phu Thuan, Phu Hai, Phu Tan, and Phu Dien). The model combined different products such as fish and shrimp. Technical assistance in feeding management and other aquaculture techniques, and financial assistance were provided to five selected households in each village or commune. For their counterpart, the households upgraded their respective ponds and provided the needed manpower. This scheme ensured sense of ownership among households as they took responsibility in conducting the experiment. The results of the model evaluation were synthesized, forming the basis for recommendations to local authorities and the community.

Water quality was evaluated for fish ponds, lagoons, and river systems in Phu Vang district. Water samples were collected from the surface and bottom layers using 5-liter (L) plastic bathometers. The samples were stored and prepared for analysis using methods described by the American Public Health Association (APHA 1995). Temperature, pH, and dissolved oxygen were measured on site; salinity, turbidity, total dissolved solids, biological and chemical oxygen demand, phosphates, nitrates, and heavy metals were measured in the laboratory.

## Analytical Procedure/Statistical Methods

A total of 203 households (directly or indirectly involved in aquaculture activities) in five communes were interviewed through quetionnaires. All data were analyzed by fitting regression equations using SPSS (version 17.0) software. ANOVA was used in this study for water environment parameters analysis. Mean was calculated as the average value and variation of data. Kruskal Wallis H Test was used for non-parametric of more than two independent factors. Significance in all statistical tests were tested at P=0.05 level.

# RESULTS

### Socio-economic Characteristics of Respondents

Of the 203 respondents interviewed, 152 were males (74.87%) and 51 were females (25.13%) (Table 3). Their ages ranged from 18 to 65 years old with average age of 44. Most (82%) are in the reproductive age (18–40 years old) and almost all were married (96.55%). This shows that majority of the working population are composed of married people from families that rely on aquaculture for their livelihood. Highest educational attainment of the respondents was high school (10.34%), but majority finished secondary school (52.21%), and the rest reached primary school (37.43%).

Although most of the households (97%) rely on aquaculture for their income, they also have other sources such as fishing (31%), farming (41.37%), livestock raising (22.6%), small business (10.8%), construction (5.9%), and others (Figure 2). Income from aquaculture, however, has significantly decreased in recent years, mainly attributed to disease outbreaks, water pollution, and natural disasters. Some farmers have stopped farming and opted to look for other sources of income.

**Table 3. Demographic characteristics of respondents**

| Characteristic | Male | | Female | |
|---|---|---|---|---|
| | Frequency 152 | % 74.87 | Frequency 51 | % 25.13 |
| Civil status | | | | |
| Single | 6 | 2.95 | 1 | 0.49 |
| Married | 146 | 71.92 | 50 | 24.63 |
| Widow | 0 | 0 | 0 | 0 |
| Age (yr) | | | | |
| 18–28 | 26 | 12.80 | 6 | 2.9 |
| 29–39 | 38 | 18.71 | 25 | 12.31 |
| 40–50 | 57 | 28.07 | 17 | 8.37 |
| 51–61 | 28 | 13.79 | 3 | 1.47 |
| 62 and above | 3 | 1.47 | 0 | 0 |
| Educational attainment | | | | |
| Primary school (grades 1-5) | 55 | 27.09 | 21 | 10.34 |
| Secondary school (grades 6-9) | 81 | 39.90 | 25 | 12.31 |
| High school (grades 10-12) | 16 | 7.88 | 5 | 2.46 |

Majority of the respondents have been involved in aquaculture for a long time, with most households practicing aquaculture for more than 10 years (71.42%). Households that engaged in aquaculture from 5 to 10 years comprise 22.66 percent. The remaining households have less than 5 years of experience in aquaculture activities (5.9%) (Table 4).

Natural disasters continue to threaten such livelihood activities. The people have limited knowledge about the climate, and when asked, 79.32 percent of them were not even aware of climate change. Only 20.68 percent of the respondents access climate change information from television and newspapers, but even they have no clear understanding of the nature and negative impacts of climate change, notably on their aquaculture-based livelihoods.

### Climatic Features of Phu Vang

Climate is an important environmental component of a territory. It has direct relationship with the inhabitants and the social economy. Changes in global climate cause sea level to rise, and natural disasters and extreme

**Figure 2. Sources of income of people in Phu Vang district**

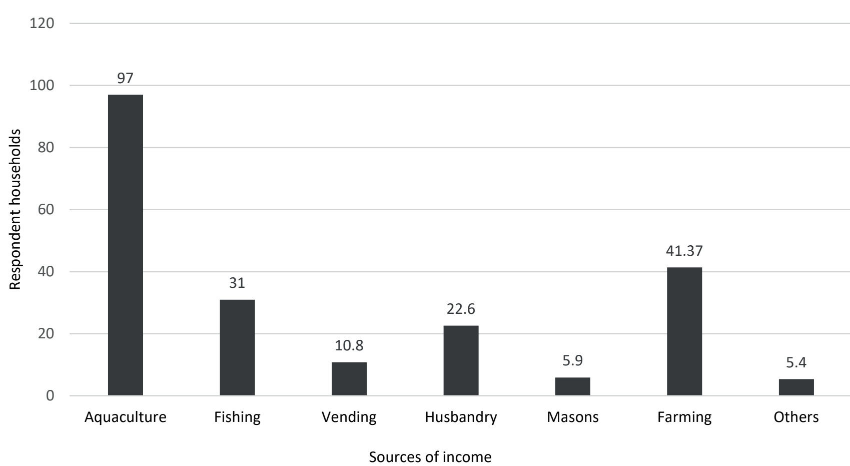



**Table 4. Experience in aquaculture of households**

| Years in aquaculture | Number of responses | Percentage |
|---|---|---|
| < 5 | 12 | 5.91 |
| 5–10 | 46 | 22.66 |
| > 10 | 145 | 71.42 |

weather events to occur more frequently in many parts of the world. All these changes inevitably have negative impacts on the sea and coastal areas of Vietnam—Thua Thien Hue province in general, and Phu Vang district in particular. Therefore, an assessment of such impacts on the region is crucial in developing strategies to mitigate their effects.

### *Temperature*

Average temperature at 25°C in Phu Vang had not increased in almost three decades between 1975 and 2012 (see Table 5). The highest temperatures occurred in the summer months from May to August (28–29.3°C), while the lowest temperatures were observed during winter (December–February). A comparison of average temperature values in Phu Vang from 1975 to 2012 showed marked decrease in the summer months, with the rate declining by 0.1°C to 0.2°C per decade. This trend is in contrast to that of the rest of the country, which had an increase of 0.2°C per decade.

Despite no significant increase in temperature in Phu Vang in the past decade, it was reported in 2012 by the Thua Thien Hue Statistical Office (TTHSO) that more frequent heat waves and prolonged cold spells had affected the health of the people as well as their agricultural and aquacultural activities.

### *Rainfall and floods*

In recent years, annual rainfall showed strong fluctuations, with average annual rainfall from the mid-90s to the present being relatively higher than in previous decades (see Table 6). Specifically, the average annual rainfall was 3,091.1 millimeters (mm) for the period 1996–2012; 2,389.7 mm for 1986–1995; and 2,867.7 mm for 1975–1985.

The highest monthly rainfall occurred in September, October, and November of each year, with the highest average rainfall observed in October (746.1 mm) (see Figure 3). The TTHSO reported an upward trend in recent years. Notable was the amount of precipitation on 2 November 1999 at 978 mm. The average rainfall throughout that same month was 2,452 mm—the highest recorded in more than 100 years. Increased rainfall intensity led to more frequent occurrence of landslides and flash floods, as well as increasingly severe floods.

Flooding is a dangerous weather phenomenon that causes heavy losses in lives and property. The TTHSO reports an average of four to five floods a year at level 2 alarm and two to three floods at the highest level of 3.

During years with occurence of the La Niña phenomenon, the number of floods and flood peaks were significantly high, most notably in 1975, 1998, and 1999.

**Table 5. Average temperature (°C) in Phu Vang (1975–2012)**

| Period | Months | | | | | | | | | | | | Average (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1975–1985 | 20.0 | 20.9 | 23.1 | 26.0 | 28.3 | 29.3 | 29.4 | 28.9 | 27.1 | 25.1 | 23.1 | 20.8 | 25.2 |
| 1986–1995 | 20.4 | 21.3 | 22.4 | 26.0 | 28.1 | 29.4 | 29.3 | 29.0 | 27.4 | 25.2 | 23.1 | 20.1 | 25.1 |
| 1996–2012 | 19.9 | 21.2 | 23.1 | 26.1 | 27.8 | 29.1 | 28.9 | 28.1 | 26.3 | 25.0 | 22.8 | 20.8 | 24.9 |
| Average | 20.1 | 21.1 | 22.9 | 26.0 | 28.1 | 29.3 | 29.2 | 28.7 | 27.0 | 25.1 | 23.0 | 20.6 | 25.1 |

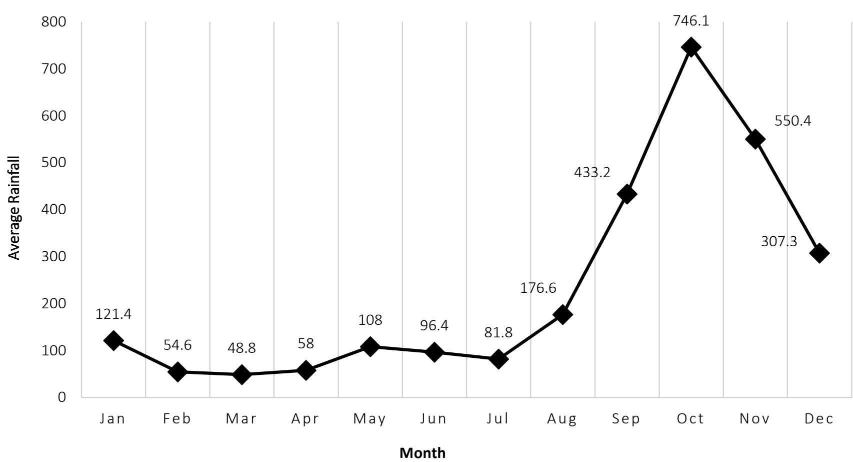
Source: TTHSO 2012

**Table 6. Average rainfall (mm) at Phu Vang district (1985–2012)**

| Period | Months | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1975-1985 | 161.3 | 62.6 | 47.10 | 51.60 | 82.10 | 116.70 | 95.30 | 104.00 | 473.40 | 795.60 | 580.60 | 297.40 | 2,867.70 |
| 1986-1995 | 81.56 | 49.13 | 29.24 | 50.02 | 107.51 | 77.76 | 68.51 | 182.48 | 288.70 | 742.23 | 455.42 | 257.18 | 2,389.70 |
| 1996-2012 | 121.47 | 52.25 | 70.17 | 72.45 | 134.47 | 94.83 | 81.76 | 243.27 | 537.49 | 700.35 | 615.16 | 367.45 | 3,091.10 |
| Average | 121.44 | 54.66 | 48.84 | 58.02 | 108.03 | 96.43 | 81.86 | 176.58 | 433.20 | 746.06 | 550.39 | 307.34 | 2,782.90 |

Source: TTHSO 2012

**Figure 3. Monthly average rainfall over the years, 1985 to 2012, Phu Vang district**




Source: DA annual reports, Phu Vang district (DARD 2012)

Meanwhile, during years affected by the El Niño phenomenon (e.g., 1982, 1987, 1991, 1994, and 1997), floods and flood peaks were at their lowest (Binh, Chuy, and Thuy 2010).

The main flood season in Phu Vang is from October to December (An and Hoang 2007). Meanwhile, floods in Thua Thien Hue province can be categorized into three:

- Early floods: small, occur from May to June, caused by heavy rains in early summer;
- Late floods: small, subside after a short period of time, occur from late December to early January, duration is longer than early floods and lasts around seven days; and
- Main floods: occur from October to December during the main rainy season in Thua Thien Hue, with about seven to eight floods a year recorded.

Almost all serious floods occurred during mid-October to mid-November, with two or three floods happening at the same time. They came with heavy storms. Historical floods in Hue were frequent with maximum water flow in Huong River noted at 12,500 cubic meter per second ($m^3/s$) and flood level in Hue at 5.81 m or 2–2.5 m from the ground at Hue City (Tu and Quang 2010).

The main causes of flooding in Hue are rains, storms, and tropical low pressure. Floodwaters come to Hue from the western mountain areas (Huong River and Bo River watersheds), causing strong water flow from the upland to the lowland. At the same time, monsoon from the sea results in higher tidal flow. Historically, flooding had left serious consequences for the people not only in PhuVang but in the entire Thua Thien Hue province (see Table 7).

### *Typhoons*

Typhoons were particularly dangerous in coastal Vietnam, including Phu Vang. Typhoon landfalls in the country had increased in recent years, particularly in Phu Vang in the 70s and 80s; there was a slight decrease in the 90s (Figure 4).

Phu Vang district was hit by eight typhoons in 1983, but in the 90s, there was an average of five typhoons a year. Binh, Chat, and Thuy (2010) found out that from 1891 to 2000 (110 years), there was an annual average of five typhoons and tropical cyclones that affected Vietnam, with one typhoon occurring in Thua Thien Hue. While the number of typhoons passing through Phu Vang has decreased in recent years, the wind intensity has increased, leaving heavy damages to life and property.

### *Sea level rise*

Statistics has shown that sea level in Hon Dau and Vung Tau has risen since 1957—water rose by 2.3 mm a year along the great plains in Vietnam over the past 40 years (Thuy and Khuoc 2012). The central coast has also seen this trend but to a lesser extent. Calculations by the authors until 2010 show that the east sea level is higher than that in 1990 by 3–15 cm. Ngoan and Tram (2010) reported that in Thua Thien Hue province, sea water rise observed during Typhoon Cecil in 1985 was 1.9 m at Thuan An commune and 1.7 m in Lang Co commune. During Typhoon Yangsane in 2006, a one-meter rise was seen. Sea water rise, combined with high tide, has made sea levels higher by 3–4 m, moving up to 2–3 km inland. It is predicted that in another 100 years, sea levels in the coastal areas of Thua Thien Hue will rise to around two meters high. This phenomenon is also manifested in the level of coastal erosion, which is getting worse. According to Binh et al (2010), sea water level in Phu Vang will continue to rise by about 30–90 cm by the end of this century.

## Impacts of Climate Change on Water Quality for Aquaculture

Sudden changes in the water quality due to water pollution can have an adverse impact on aquatic life, which subsequently affects overall productivity and the lives of the people. Therefore, a study on the conditions affecting water quality brought about by climate change is crucial.

The water source for aquaculture was identified to be an area of more than 6,800 ha at the Tam Giang-Cau Hai lagoon. Water samples were taken to determine water quality by measuring the following parameters: water temperature, potential of hydrogen (pH), salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), turbidity, phosphate, ammonia, nitrate, and heavy metals (copper, lead, zinc, and cadmium) (see Table 8).

### *Water temperature*

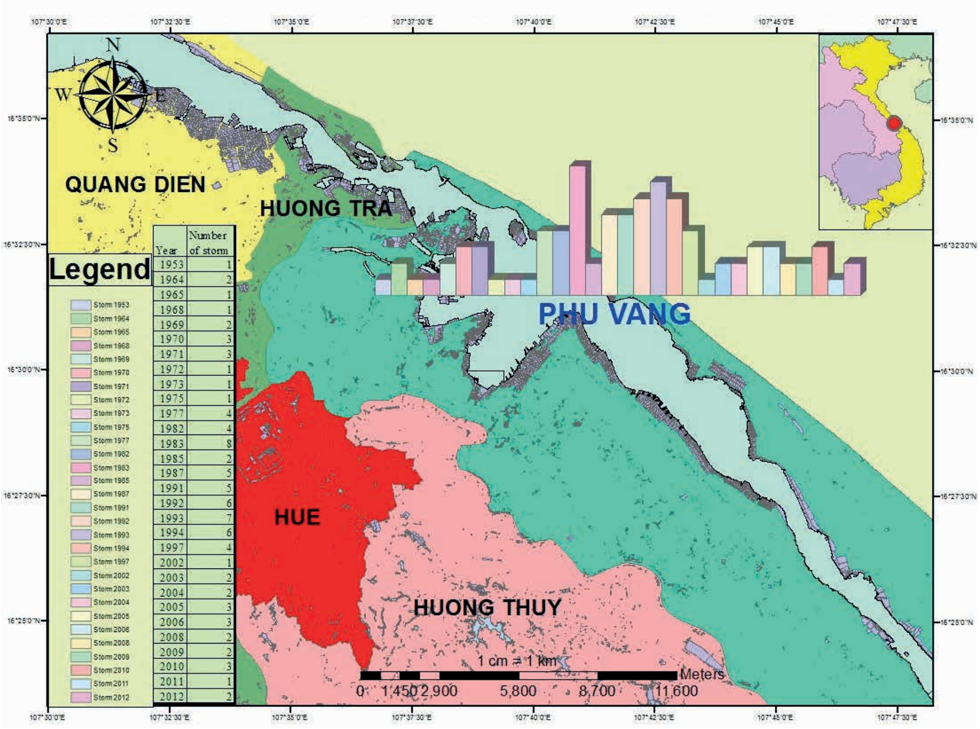
The effect of temperature on water bodies and resident aquatic organisms is of basic importance as, to some degree, it determines the productivity of aquatic life. In relation to factors for overall productivity, temperature affects metabolic rates of aquatic organisms, solubility of oxygen in water, and distribution of nutrients throughout the water column through water movement, to name a few. The suitable temperature for the growth of most aquatic animals is in the range of 20–30°C (Binh, Chat, and Thuy 2010).

**Table 7. Historical floods from 1894 to 1999 at Thua Thien Hue province**

| Month/year | Damage |
|---|---|
| May 1894 | Damaged villages and killed many people |
| October 1897 | Closed Eo estuary (Hoa Duan) and Sut estuary (Thuan An) |
| September 1904 | Broke four spans of Trang Tien bridge and Phuoc Duyen tower at Linh Mu pagoda; Second one closed Eo and Sut estuaries |
| October 1928 | Broke the Thuan An dam |
| September 1930 | Broke Tu Hien and Thuan An estuaries |
| September 1980 | Killed 173 people |
| July 1981 | Destroyed 40,000 houses |
| October 1983 | Killed 252 people and hurt 115 |
| October 1985 | 604 killed, 234 hurt, 98 missing |
| October 1989a | Killed 140 people |
| October 1989b | Killed 53 people and hurt 766 |
| October 1992 | Killed 7 people |
| November 1998 | Killed 31 people |
| November 1999 | Killed 373 people |

Source: An and Hoang 2007

**Figure 4. Number of typhoons that hit Phu Vang district over the years**




Source: An and Hoang 2007

**Table 8. Factors affecting water quality in an aquaculture pond in the Tam Giang Cau Hai lagoon system, Phu Vang District**

| Water Quality | Lowest | Highest | p >0.05 | Remarks |
|---|---|---|---|---|
| Water temperature | October 27.84 ± 0.27 | April (30.20 ± 0.44) | Not significant in temperature and between seasons | Temperature is suitable for aquaculture |
| pH | October 6.74 ± 0.18 | June 7.62 ± 0.30 | Significant between seasons, but not significant between sites | Ph is within state-prescribed range for aquaculture |
| Salinity | October 8.6 ± 0.54 | June 12.73 ± 1.04 | Significant between seasons | Decrease in salinity is not favorable to growth of aquatic organisms with narrow salinity tolerance |
| Dissolved Oxygen (DO) | March 5.44 ± 0.20 mg/L | October 5.74 ± 0.15 mg/L | Not significant between months or between sites | DO concentrations higher than minimum limit for aquaculture |
| Biochemical oxygen demand (BOD) | March 2.38 ± 0.54 mg/L | October 2.80 ± 0.25 mg/L | Not significant between months | BOD values were within optimal limits |
| Chemical oxygen demand (COD) | June 6.12 ± 0.38 mg/L | October 11.62 ± 2.86 mg/L | Significant difference between months but not significant between sites | COD values exceed limit set by the regulation; also indicates degree of pollution in the lagoon |
| Total dissolved solids (TDS) | March 15.5 ± 2.69 mg/L | October 22.68 ± 3.38 mg/L | Significant difference between months and sites | TDS values were within range of acceptable standards |
| Turbidity | April 4.98 ± 0.63 Nephelometric Turbidity Unit (NTU) | October 7.56 ± 0.19 NTU | Significant between September and October only; also significant between sites during that period | |
| Phosphate ($PO_4^{-3}$) | October 0.09 ± 0.14 mg/L | May 0.26 ± 0.30 mg/L | Significant between March, April, May and June, but not between sites | |
| Ammonia ($NH_4^+$) | September 0.070 ± 0.021 | August 0.088 ± 0.16 | Not significant between months and between sites | Ammonia concen-tration was within acceptable standards, except in sites where it exceeded safe levels in March and April |
| Nitrate ($NO_3$) | November 0.16 ± 0.88 | July 0.128 ± 0.030 | Not significant between months and sites | |

Continued: **Factors affecting water quality in an aquaculture pond in the Tam Giang Cau Hai lagoon system, Phu Vang District**

| Water quality | Lowest | Highest | p >0.05 | Remarks |
|---|---|---|---|---|
| Heavy metals | | | | |
| Copper (Cu) | March 21.66 ± 1.96 μ g/L | October 26.30 ± 1.22 μ g/L | Not significant between months and between sites | |
| Lead (Pb) | April 0.49 ± 0.11 μ g/L | September 0.63 ± 0.06 μ g/L | Not significant between months and between sites | Pb content is within allowable limits. |
| Zinc (Zn) | April 7.56 ± 1.17 μ g/L | September 8.10 ± 0.33 μ g/L | Not significant between months | Zn values optimal for aquaculture because they are below water quality standards. |
| Cadmium (Cd) | April 0.49 ± 0.11 μ g/L | September 0.06 ± 0.63 μ g/L | Not significant between months and between sites | Cd values were within allowable range. |

The monthly average temperature at the study sites ranged from 27.50°C to 30.50°C. The monthly temperature difference was not large. Average temperature was highest in April (30. 20 ± 0.44) and lowest in October (27.84 ± 0.27). Statistical analysis showed no significant difference in temperature (p>0:05) and no difference between the dry season (March–August) and rainy season (September–October) (p<0.05). In general, the temperature is suitable for aquaculture and reflects similar trends not only in Phu Vang district or Thua Thien Hue province, but in the country in general (see Table 8).

***pH***

The pH of water is a volatile element and in the lagoon, pH is dependent on many factors such as seasons and tides. Drinking water from the river flows into the lagoon.

The average monthly pH value ranged from 6.5 to 7.8. pH and was highest in June (7.62 ± 0.30) and July (7:58 ± 0.34), decreasing during the rainy season, and finally registering the lowest value in October (6.74 ± 0.18). In general, pH values in the study sites were almost uniform and had no statistical difference (p>0.05). However, there was significant difference between the dry-season pH and rainy-season pH (p<0.05). The water pH in all study areas were well within the state-prescribed range for aquaculture purposes at pH 6.5–8.5 (Table 8).

***Salinity***

Salinity has obvious variation between the rainy season and the dry season. In the dry season (March–July), salinity ranged from 11 to 13 parts per thousand (ppt), whereas in the rainy season (August–October) salinity ranged from 8 to 11 ppt. Salinity is lowest in October (8.6 ± 0.54). Results of data analysis showed no statistical difference ($p>0.05$). However, the difference was statistically significant between the rainy season and the dry season ($p<0.05$). This is true of Phu Vang weather; rainy season in the district is usually characterized by low salinity. This decrease in salinity does not favor the growth of aquatic organisms, especially those species with narrow salinity tolerance (see Table 8).

### *Dissolved oxygen*

Monthly average DO was relatively high, with no significant changes throughout the study period. DO ranged from 5.20 to 6.0 milligrams per liter (mg/L).The highest average DO was seen in October (5.74 ± 0.15 mg/L) and the lowest was observed in March (5.44 ± 0.20 mg/L). Fluctuations in DO concentration were not much. Statistical tests showed no difference between study sites ($p>0.05$) and between months ($p>0.05$). When compared with Circular No. 44/TT-BNNPTNT (Ministry of Agriculture and Rural Development 2010) requirements, the DO concentrations measured in this study were higher than the minimum limit (3.5 mg/L) set for aquaculture (see Table 8).

### *Biochemical oxygen demand*

BOD is the key parameter used to assess the extent of water pollution by organic substances attributed to microbial degradation in aerobic conditions. The BOD index indicates the amount of bacteria that consumes oxygen in relation to loads of organic matter in polluted water. BOD concentration was highest in October (2.80 ± 0.25 mg/L) and lowest in March (2.38 ± 0.54 mg/L). Although there were differences between months, they were not statistically significant (p>0:05). BOD values were within optimal limits (<30 mg/L) (see Table 8).

### *Chemical oxygen demand*

The vast majority of organic compounds in water have redox potential properties. Chemical oxygen demand (COD) is defined as the amount of oxygen (expressed in grams or milligrams oxygen [$O_2$] per unit volume) required for the chemical oxidation of organic matter in a body of water turning it into $CO_2$ and $H_2O$. The COD value allows the evaluation of total organic compounds that can be oxidized, therefore COD values are always higher than BOD values. COD is a widely used parameter to determine the level of organic matter in water, including biodegradable organic matter and other compounds with higher resistance to biodegradation, and is thus, an important indicator of water pollution (Hop, Khoa, and Nghi 2010).

COD monthly average ranged from 5.5 to 15.1 mg/L. COD concentration increased over the months, with the highest seen in October (11.62 ± 2.86 mg/L) and the lowest in June (6.12 ± 0.38 mg/L).

Statistical tests showed a statistical difference in average COD values between months ($p>0.05$). This difference was most evident between September and October. However, there was no statistical difference between study sites ($p>0.05$) (see Table 8).

When compared with national water quality standards (Circular No. 44/2010/TT-BNNPTNT), COD values were found to exceed the limits set by the regulation numerous times (<3 mg/L). This also shows the degree of pollution in the Tam Giang-Cau Hai lagoon today.

***Total dissolved solids***

Soluble solids are usually inorganic minerals; sometimes they contain organic materials such as chloride, carbonate, nitrate, sulfate, and phosphate, and elements such as Na, K, Ca, Mg, and Fe. Water with high levels of soluble substances is said to be unsuitable for use in daily life (Hop et al. 2007). It is also not used for irrigation in agriculture for long durations because it can increase soil salinity. Water with highly dissolved solid content can make water microorganisms necrotic.

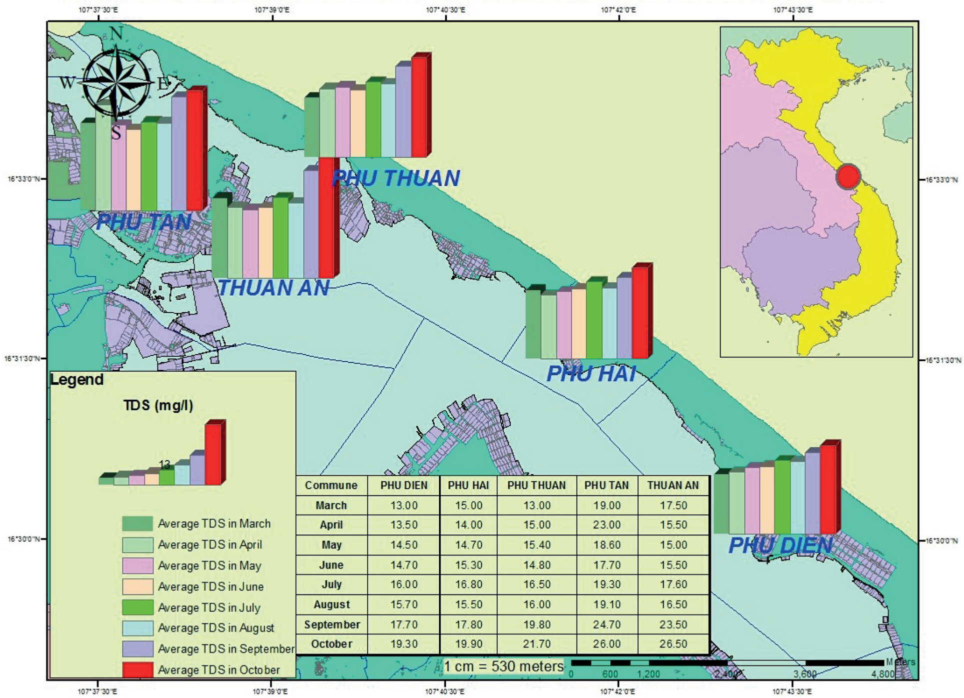
Large variations in TDS content were observed. The average value of TDS ranged from 13 to 26.50 mg/L, increasing from March to October (Figure 5). TDS average value was highest in October (22.68 ± 3.38 mg/L) and lowest in March (15.5 ± 2.69 mg/L). There were significant differences between study sites and between months throughout the duration of the study ($p<0.05$). In addition, TDS differences between sampling points were found to be statistically significant ($p<0.05$). TDS values were within the range of acceptable standards (<1000 mg/L). However, high TDS during rainy season showed influence of weather factors on water quality in the lagoon (see Table 8).

***Turbidity***

Turbidity refers to the ability to inhibit the penetration of sunlight into the water column, usually due to the presence of colloids, clay, algae, and microorganisms. As it reduces the transmission of light in water, it becomes an essential criterion used to assess pond condition.

Average monthly turbidity ranged from 4.20 to 10.50 Nephelometric Turbidity Unit (NTU). The highest average turbidity was in October (7.56 ± 0.19 NTU), while the lowest was in April (4.98 ± 0.63 NTU). There was a gradual increase

**Figure 5. Monthly changes in total dissolved solids in the study sites**




| Commune | PHU DIEN | PHU HAI | PHU THUAN | PHU TAN | THUAN AN |
|---|---|---|---|---|---|
| March | 13.00 | 15.00 | 13.00 | 19.00 | 17.50 |
| April | 13.50 | 14.00 | 15.00 | 23.00 | 15.50 |
| May | 14.50 | 14.70 | 15.40 | 18.60 | 15.00 |
| June | 14.70 | 15.30 | 14.80 | 17.70 | 15.50 |
| July | 16.00 | 16.80 | 16.50 | 19.30 | 17.60 |
| August | 15.70 | 15.50 | 16.00 | 19.10 | 16.50 |
| September | 17.70 | 17.80 | 19.80 | 24.70 | 23.50 |
| October | 19.30 | 19.90 | 21.70 | 26.00 | 26.50 |

Source: An and Hoang 2007

noted from April to October. Results of statistical analysis showed that the turbidity difference was significant between September and October compared with that between other months ($p<0.05$); this difference was also found between study sites (see Table 8).

### *Phosphate*

Phosphate content is one of the criteria used to evaluate water quality. The concentration of phosphate in unpolluted waters is often less than 0.01 mg/L. Phosphate levels in water have a bearing on marine biological productivity, especially that of fish and shrimp. Also, phosphorus is one of the important nutrients needed for the growth of plants, algae, and microorganisms in water (Hop et al. 2007).

Notable variations in average value of phosphate were observed through the months in the study area. Highest average was seen in May (0.26 ± 0.30 mg/L), and the lowest was found in October (0.09 ± 0.14 mg/L). The average value of phosphate did not significantly change between study sites, except for a sharp increase in June (0.80 mg/L) specifically at Phu Hai commune.

Statistical tests showed that phosphate content differed in March, April, May, and June. There was a decrease in the rainy months of July, August, September, and October ($p<0.05$) (see Table 8).

### *Ammonia*

Ammonia is considered toxic to aquatic animals. Dissolved ammonia in water, formed by the decomposition of nitrogen-containing organic compounds, should always be closely monitored in aquaculture.

Results show that monthly ammonia values averaged 0.05–0.25 mg/L. The highest value was observed in August (0.088 ± 0.16) and the lowest was noted in September (0.070 ± 0.021). Fluctuations in ammonia content during the study period were not high and there was no statistical difference between months ($p>0.05$) or between study sites (see Table 8).

Ammonia concentrations in the water bodies studied were mostly within acceptable standards (<0.1 mg/L). However, in some areas such as Thuan An and Phu Tan, ammonia concentrations exceeded safe levels in March and April. This also reflects the level of toxic air pollution in the locality during the dry season.

### *Nitrate*

Nitrate is the end product of the decomposition of nitrogen contained in the wastes of aquatic animals. Levels suitable for fishponds range from 0.1 to 10 mg/L. According to Hop et al. (2007), high nitrate levels will not be toxic to fish, but combined with phosphorus, can cause eutrophication. Large phytoplankton blooms can occur, causing changes in water quality that are detrimental to aquatic animal life.

Results of nitrate content analysis showed no significant change; the range was from 0.05 to 0.15 mg/L. In particular, the highest average value of nitrate was in July (0.128 ± 0.030) and lowest was in November (0.16 ± 0.88). Statistical tests showed no significant difference between months and study sites ($p>0.05$).

### *Heavy metals*

Heavy metals in the water were evaluated because they have a direct effect on human health. Heavy metal pollution in the water environment at Phu Vang was mainly attributed to human activities. Their concentrations in the water also fluctuate when there is flooding, with heavy metal concentrations increasing in areas where rivers drain out (Hop, Khoa, and Nghi 2010).

### *Copper*

From March to October, copper (Cu) content in the water increased gradually. Average Cu content was lowest in March (21.66 ± 1.96 micrograms per liter [μ g/L]) and highest in October (26.30 ± 1.22 μ g/L). However, differences between months and study sites were not significant (p>0.05) (see Table 8).

### *Lead*

Lead (Pb) is a toxic metal also covered in the study. The average monthly Pb content ranged from 0.40 to 0.90 μ g/L. Highest average is in September (0.63 ± 0.06 μ g/L) and lowest is in April (0.49 ± 0.11 μ g/L). Pb content increased in the rainy season. However, statistical tests showed no significant difference between months (p>0.05) and between the sites in the study area. When compared with the country's water standards, Pb content in the study area was found to be within allowable limits (<50 μ g/L) (see Table 8).

### *Zinc*

Average monthly values of zinc (Zn) ranged from 6.0 to 11.30 μ g/L. Zn content was lowest in April (7.56 ± 1.17 μ g/L) and highest in September (8.10 ± 0.33 μ g/L). However, results showed no statistically significant change in Zn content between the months covered by the study period (p>0.05). Zn values were in the range optimal for aquaculture as they were much below the water quality standards of Vietnam (Zn <50 μ g/L) (see Table 8).

### *Cadmium*

Average cadmium (Cd) content analysis showed a range of 0.32–0.73 μ g/L. September registered the highest Cd content (0.06 ± 0.63 μ g/L) and April had the lowest (0.49 ± 0.11 μ g/L). Cd tended to increase during the rainy season (September and October), but this was negligible. No significant difference in average Cd content was found between months (p>0.05). Cd values, when compared with water quality standards for aquaculture, were within the allowable range (<5 μ g/L) (see Table 8).

## Impacts of Climate Change on Water Quality

Many researchers have recently shown interest in studying the impacts of climate change on water quality such as in rivers, ponds, and marshes. Delpla et al. (2009) had stated that climate change impacts on water quality directly or indirectly. Increased water temperature would significantly degrade water quality, especially during droughts when surface evaporation increases. In addition, increased rainfall due to climate change subsequently increases surface flow, which leads to higher concentrations of dissolved compounds in the water. Cuong (2012) points to temperature, rainfall, and evaporation as the basic parameters for assessing impact of climate change on water quality.

This study has shown that climate change has negative impacts on water quality for aquaculture, particularly in the study area. Extreme weather events triggered by climate change such as prolonged flooding, had reduced the salinity of usually brackish water environments. The decreased salinity and the prolonged rainy season had a strong impact on the ecosystems and on the biodiversity of the lagoon. Saltwater fish species migrate from the lagoons to the sea during rainy season. Freshwater species also migrate from the rivers to the lagoons.

The people confirmed that flooding or the unusually prolonged rains affected water quality, especially its salinity. Salinity values <3 ppt like that found in Phu Thuan and Thuan An communes, had resulted to fish-kill in the ponds. These species—rabbitfish, kinh, and mullet—have high economic value, hence, fish-kills greatly impact on farmers' income.

The dry season brings more frequent and unusual heat waves, which leads to rising water temperature. Evaporation takes place and causes water levels in the ponds to decrease. Other environmental factors are likewise affected—e.g., when water temperatures rise, pH and salinity increase, but DO decreases due to intensification of aquatic respiration. This greatly affects the growth and survival of fish and shrimps.

A study of Tu and Quang (2010) has shown that high water temperatures intensified evaporation in the lagoon, making water level lower than that in the sea. While the phenomenon of sea level rise combined with high tide makes seawater flow into the lagoon through the estuary, consequent increase in water salinity in the lagoon creates salinity stratification. Sometimes, there is salinity difference of about 2–3 percent between the surface and bottom waters in the Tam Giang lagoon in the dry season. This greatly affects the small species that have adapted to saltwater, especially water plants and benthic species with poor ability to move (Tu and Quang 2010).

Water parameters such as water turbidity, TDS, COD, and heavy metals such as Cu, Cd, Zn, and Pb were also found to be higher in the rainy season. Their levels tend to increase during and after a flood. An and Hoang (2007) showed floods occurring more frequently and with greater intensity in recent years, along with pollution and shallowing of the waters in the Tam Giang-Cau Hai lagoon system. Researchers had estimated about 1.1 million tons (t) of sediments coming from the surrounding area of the lagoon, of which approximately 30 percent would follow the water flow into the sea. The remaining 70 percent (774,000 t) accumulate in the Tam Giang-Cau Hai lagoon. This is a sediment deposition rate of 2.4 mm a year, contributing to accelerated water pollution and the subsequent decline of the lagoon.

## Impacts of Climate Change on Aquaculture

### *Status of aquaculture in Phu Vang district*

As a coastal district, Phu Vang's key economic industry is aquaculture. However, several factors had caused significant changes in the industry in recent years.

#### *Aquaculture area*

In the last 10 years (2002–2012), there were no significant changes in area devoted to aquaculture, except for significant increase from 2002 to 2004 (1,471–2,017 ha). During this period, tiger prawn raising thrived, people dug ponds, and some households even converted their agricultural land for use in aquaculture. A survey showed brackish water area jumping from 1,367 ha in 2002 to 1,838 ha in 2004, majority of which was utilized for intensive shrimp cultivation (DARD 2012).

However, the massive development of shrimp farming caused water pollution and disease outbreaks. These resulting conditions aggravated by frequent natural disasters such as droughts, floods, and storms, are all detrimental to shrimp farming. Culture production decreased and the high level of risk caused heavy losses to farmers. Aquaculture development slowed down, and brackish water area decreased to 1,792 ha in 2005 and to 1,780 ha in 2007. From 2008 to 2012, the area has increased but it was not to any significant scale (see Table 9).

**Table 9. Aquaculture area of Phu Vang district, 2002–2012**

| Year | Aquaculture area (ha) | | Total |
|---|---|---|---|
| | Brackish water | Fresh water | |
| 2002 | 1,367.0 | 104.6 | 1,471.6 |
| 2003 | 1,529.6 | 121.1 | 1,650.7 |
| 2004 | 1,838.1 | 179.3 | 2,017.4 |
| 2005 | 1,792.0 | 123.1 | 1,915.1 |
| 2006 | 1,874.1 | 164.3 | 2,038.4 |
| 2007 | 1,779.9 | 177.3 | 1,957.2 |
| 2008 | 1,979.6 | 192.9 | 2,172.5 |
| 2009 | 1,934.2 | 191.5 | 2,125.7 |
| 2010 | 1,953.6 | 206.7 | 2,160.3 |
| 2011 | 1,918.3 | 238.7 | 2,157.0 |
| 2012 | 1,974.2 | 245.1 | 2,2193 |

Source: DARD 2012

### *Yield and productivity*

Yield and aquacultural productivity of Phu Vang district in the 10-year period are shown in Table 10. Aquaculture production of the entire district from 2005 to 2012 had a downward trend compared with that in 2002–2004. Brackish water aquaculture yield was at its highest level in 2004 at 4098.9 t; productivity was 2.23 t/ha. However, production and productivity of brackish water aquaculture had decreased gradually since 2005, with the lowest yield (1,600 t) seen in 2007 and productivity at 0.89 t/ha. The figures in 2010 were 1,742.1 t and 0.89 t/ha, respectively. Yield was calculated on shrimp aquaculture in brackish water and fish aquaculture in freshwater. In the past decade, average yield of freshwater fish in the whole district went down to 143.5 t; productivity was 0.58 t/ha. In 2005, freshwater fish production was 639.7 t and productivity was 5.1 t/ha.

A look at the secondary data revealed that in the 2002–2004 period, average yield of shrimp increased in some areas such as Phu Tan, Thuan An, Phu Thuan, Phu Xuan, and Phu My communes. This was due to intensive cultivation of shrimp—stock fingerling density used then was 30–40 fingerlings per square meter ($m^2$) and productivity reached 3–5 t/ha per crop. However, from 2005 to the present, productivity of shrimp aquaculture in lagoon areas decreased. Average yield has been only 1 t/ha per crop. Recently in Thua Thien Hue province, a number of districts such as Quang Dien, Phu Loc, and Phong Dien have cultivated *Penaeus vannamei* shrimp in the coastal sandy areas. The yield was high with an average productivity of 10–12 t/ha per crop (two to three crops a year). This resulted in a slight increase in average yield of shrimp across the province.

**Table 10. Aquacultural productivity and yield in PhuVang, 2002–2012**

| Year | Yield (t) | | Total (t) | Productivity (t ha-1) | | Total (t ha-1) |
|---|---|---|---|---|---|---|
| | Brackish water | Freshwater | | Brackish water | Freshwater | |
| 2002 | 2,009.5 | 298.1 | 2,307.6 | 1.47 | 2.85 | 4.32 |
| 2003 | 2,753.3 | 387.5 | 3,140.8 | 1.80 | 3.20 | 5.00 |
| 2004 | 4,098.9 | 638.1 | 4,737.0 | 2.23 | 3.81 | 6.04 |
| 2005 | 2,300.3 | 639.7 | 2,144.3 | 1.28 | 5.1 | 6.38 |
| 2006 | 2,059.6 | 632.5 | 2,576.6 | 1.09 | 3.84 | 4.93 |
| 2007 | 1,600.0 | 600.0 | 2,745.4 | 0.89 | 3.38 | 4.27 |
| 2008 | 2,502.9 | 424.8 | 2,927.7 | 1.26 | 2.20 | 3.46 |
| 2009 | 2,437.7 | 405.7 | 2,843.4 | 1.26 | 2.11 | 3.37 |
| 2010 | 1,742.1 | 457.9 | 2,200.0 | 0.89 | 2.21 | 3.10 |
| 2011 | 2,411.8 | 280.3 | 2,692.1 | 1.25 | 1.17 | 2.42 |
| 2012 | 2,796.5 | 143.5 | 2,940.0 | 1.41 | 0.58 | 1.99 |

Source: DARD 2012

*Species and methods of aquaculture*

Phu Vang district adapted species diversity in aquaculture to support its economic goals—i.e., transformation from specialized to interspersed multiple shrimp species to ensure profitable aquaculture and sustainability (DARD 2012). Among the diverse species are *P. vannamei* (mainly under intensive farming in Vinh An commune), blue crab, spotted scat, rabbitfish, kinh, mullet, snapper, seabass, and grouper. The main culture is innovative extensive farming, a form of polyculture that combines multiple species (84%); intensive shrimp farming areas decreased to 16 percent. Meanwhile, from 2001 to 2004, intensive culture of shrimp was done in 76 percent of the total brackish water area throughout the district (DARD 2012). However, some intensive farming of *P. vannamei* was done in sandy ponds: 150 breeds/m$^2$ and yield of 10–13 t/ha in Vinh An commune.

The aquaculture methods used were also diversified, ranging from farming fish in ponds, cages, cement tanks, and pen culture, to mollusk farming, and seaweed cultivation. Freshwater fish is mainly farmed in cages. Farming fish in ponds accounted for 83 percent, whereas farming fish with intercropping or crop rotation–fish-rice–accounted for 17 percent (DARD 2012).

*Diseases, water pollution, and natural disasters*

Shrimp diseases have started to appear in the respective districts since 2005, in more than 5 percent of the farming area (Table 11). The main reason was farming at very high densities (30–40 breeds/m$^2$) (DARD 2012). Other contributing factors were improper variety selection, poor infrastructure, and limited technical knowledge of farmers. The disease situation was further complicated by contamination of the lagoon environment, erratic weather, floods arriving earlier than usual, untimely information dissemination, and implementation of new hydropower projects. These posed challenges to making environmental

**Table 11. Shrimp disease status in Phu Vang district, 2005**

| Commune | Households (no.) | Ponds (no.) | Area (ha) | Species (x 103) |
|---|---|---|---|---|
| Vinh Ha | 21 | 22 | 9.90 | 130.0 |
| Phu Da | 6 | 13 | 4.95 | 71.6 |
| VinhThanh | 4 | 6 | 1.24 | 13.4 |
| Vinh An | 24 | 46 | 11.45 | 80.9 |
| Phu Xuan | 14 | 19 | 9.30 | 128.0 |
| Vinh Phu | 2 | 2 | 0.70 | 2.0 |
| Vinh Xuan | 22 | 24 | 8.50 | 63.0 |
| Total | 93 | 132 | 46,04 | 488.9 |

Source: DARD 2012

forecast and in providing technical recommendations to overcome difficulties in the aquaculture sector.

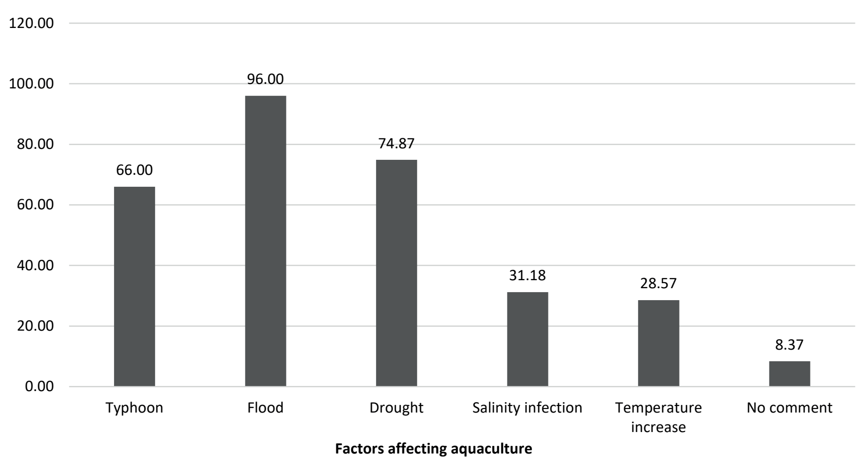
*Infrastructure for aquaculture*

Infrastructure to support aquaculture in Phu Vang district has neither been synchronously put in place nor in accordance with technical standards. For example, there was no system of settling ponds and no facilities for wastewater treatment. Additionally, pond dikes were not solid, especially in the low-tide area. Up to 40 percent of the shrimp ponds were not properly designed, and pipes used for water supply were used for drainage at the same time, further spreading diseases. This situation is evident in Phu Tan, Thuan An, and Phu Thuan communes.

## Climate Change Impact

Climate change has a huge impact on aquaculture because it results to changes in aquaculture area, affects yield and farm productivity, and destabilizes the ecological structure of the livestock and crop system. Factors such as rising temperatures, floods, droughts, and sea level rise had in recent years shown a direct impact on aquaculture in Phu Vang. Survey results show 96 percent of household respondents reporting that flooding has a great negative impact on aquaculture, reducing productivity and destroying infrastructure. The other factors that negatively impact on aquaculture are prolonged drought (74.87%), storms (66%), rising sea level (31.18), and increase in temperature (28.57) (Figure 6).

**Figure 6. Factors that affect aquaculture activities**



### *Impacts of drought and high temperatures*

Manifestations of climate change such as droughts and prolonged heat increased air and pond temperatures. Temperature plays an important role in the growth and development of organisms in general and of aquaculture species in particular. Heat makes water temperature rise to excessive levels and kills farmed aquatic species. While temperature has not risen in Phu Vang in recent years, prolonged hot summers have greatly impacted on aquaculture activities, with water levels in ponds falling rapidly due to strong evaporation (see Table 5). This has led to additional investment in water pumps for shrimp culture in ponds. Rising temperatures also make aquatic animal respiration more vigorous, with the probability of localized hypoxia occurence increasing as well. If not treated on time, this will cause fish and shrimp to die off. Furthermore, rising temperatures do not only affect the health of fish species but the environment because it allows harmful microorganisms to grow.

Prolonged heat incidence occurs from May to August each year when average monthly temperature rises to 29°C (see Table 5). The highest air temperature is measured in days. Sometimes, up to 39°C lasts for several days, causing severe damage to agriculture and aquaculture in the district.

### *Impacts of natural disasters*

Extreme weather phenomena such as floods have been occurring early in recent years, and cyclones and storms have also been occuring more frequently than in previous years. Storms usually occured in September, but in recent years, tropical depressions would occur any month of the year. Furthermore, storms have happened more frequently and more intensely. Up to 95 percent of the households interviewed said that flooding occurs frequently and unexpectedly; the remaining 5 percent claimed that floods come earlier. The farmers did not have timely solutions for these occurences; as a result, many households suffer huge losses in their fish and shrimp business.

Natural disasters, unstable weather, pollution, and poor quality breeds cause large variations in productivity. Typhoons that occur with unusual intensity have destroyed irrigation facilities for aquaculture. An example is storm No. 9 in 2007. Heavy rains combined with high tide caused massive flooding in the area that brought huge losses among fish farmers. The system of lakes and dams for brackish water aquaculture was also damaged, which caused major setbacks in aquaculture in Phu Vang district (DARD 2012).

Prolonged rain lasting 3–4 months also caused low salinity and unsuitable temperature that resulted to slow fish and shrimp growth. In the same way, in

July and August, prolonged heat and increased salinity slowed down fish growth, which led to extended culture periods.

### *Impacts of sea level rise (high tides) and salinity intrusion*

Analysis of sea level data in Hon Dau and Vung Tau cities from 1957 up to the present revealed the reality of sea level rise. Water level rose by 2.3 mm a year along the major deltas in Vietnam during the past 40 years (MNRE 2007). The same phenomenon happened in the central coast, but to a lesser extent. Calculations made by researchers point to the fact that sea level rise in 2010 was higher than that in 1990 from 3 to 15 cm (Tu and Quang 2010). Maximum water level in Thua Thien Hue province during 1960–2000 was 1.85 m. Therefore, Thua Thien Hue province was the most affected, with data on flooded areas at 260.3 $km^2$, 289.7 $km^2$, and 320.3 $km^2$. The corresponding sea level rise of 50 cm, 75 cm, and 100 cm caused major damage to agriculture and aquaculture.

In Phu Vang district, rising sea levels strongly impacted on the lagoon system that has been used for aquaculture. The Agriculture Department in Phu Vang district predicts that if sea level rises by an additional one meter, the entire bank prevention system and cofferdam in Phu Thuan, Phu Hai, Phu Tan, Vinh An, and Phu Xuan communes can no longer be used because many aquaculture areas would have saline water. Rising sea levels and flood tides prevented floods from draining, causing prolonged flooding in large areas in Phu Vang district in 1989.

## Aquaculture Models for Adaptation to Climate Change

Five models of climate change adaptation for aquaculture were developed for use in Phu Tan, Thuan An, Phu Thuan, Phu Hai, and Phu Dien communes. These communes have developed aquaculture activities in Phu Vang district.

Because actual surveys showed that monoculture of *P. monodon* in Phu Vang was not effective in recent years, a polyculture model was developed, in which many species have the ability to adapt to local climate.

### *Basis for developing models of polyculture and techniques*

The aquaculture production model should be based on actual conditions of the locality—e.g., infrastructure for aquaculture, pond conditions, water resources and water quality for aquaculture, species, breeding animal, climatic conditions, investment capacity of the people, and compliance with provisions of the law for aquaculture in the area.

*Ponds*

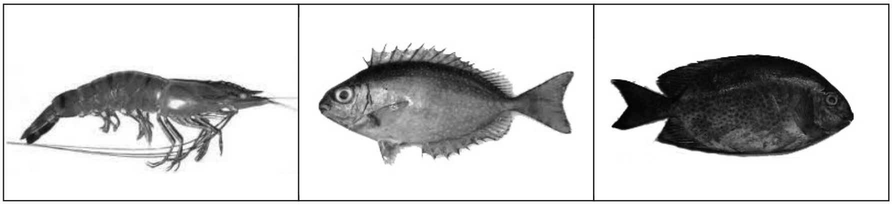
Ponds should have an adequate area for farming to be effective. Pond area suitable for polyculture models measures from 3,000 to 10,000 $m^2$; hence, a pond area of 5,000 $m^2$ was chosen for these models. The pond area has been designed and built mostly in the locality. Ideally, ponds should have separate intake and outtake sluice gates, and water level height must at least be one meter. The aquaculture model involves a semi-intensive culture, which requires ponds to have a water system fan or aeration.

**Figure 7. A sample dam used to assess the aquaculture model**

*Species*

Species for use in aquaculture must meet these criteria: high economic value, abundant breeding source, easy to buy, fast growth rate, short culture period, and ability to adapt well to local climate conditions. Thus, two traditional species were selected—rabbitfish *(Siganus guttatus)* and black tiger shrimp *(P. monodon)*. A species of native fish, kinh *(Siganus canaliculatus)*, was also chosen (Figure 8).

**Figure 8. Species used in the polyculture model**



| Black tiger shrimp (*Penaeus monodon)* | Kinh (*Siganus canaliculatus)* | Rabbitfish (*Siganus guttatus)* |
|---|---|---|

These species were distributed in the Tam Giang-Cau Hai lagoon. They can grow well at salinities from 5 to 37 ppt, with temperature of 24–33°C and pH of 7–8.5. Kinh and rabbitfish are herbivorous with preference for seaweeds, but they can also eat commercial feed. Because these species do not prey on each other, they were placed in the same polyculture pond. Fish has the ability to grow fast and can be harvested in four months. Sources of rabbitfish, kinh, and black tiger shrimp are abundant and easily found in Phu Vang and neighboring districts. Table 12 shows the density, size, and feed use for these species.

*Pond management*

Water parameters such as temperature, pH, salinity, and DO were measured twice a day at 7:00 a.m. and 2:00 p.m. Other parameters such as BOD, COD, ammonia, NO3, TDS, and turbidity were measured twice a month. Fish were fed twice a day (7–8 a.m. and 5–6 p.m.), mostly with commercial feed (daily feed intake of 10% of body weight), and supplemented with seaweeds once a week (Table 12). Pond water was replaced twice a month, with not more than 30 percent of the water remaining in the pond at each time.

### ***Results pertaining to environmental parameters of the pond***

Water temperature, pH, salinity, and DO were all within the appropriate range and had almost no significant changes during the culture period. There were differences between parameters (BOD, COD, ammonia, NO3, Cb, Cu, Zn, and Cd) inside and outside of the pond, but they were within the limits allowed for aquaculture (see Table 8).

### ***Results on growth, survival, productivity, and yield***

Shrimp and fish rapidly grew after more than four months of culture. The average individual weight of shrimps in the pond was 17.26 g, rabbitfish weighed 208 g, and kinh weighed 53.3 g. The highest shrimp weight was seen in Phu Hai (17.8 ± 2.1 g), and the lowest was observed in Phu Dien (16.6 ± 2.5 g). Statistical analysis showed no differences between the ponds in Phu Tan, Phu Hai, Phu Thuan, and Thuan An. However, there was statistical difference between the average weight of shrimp in those ponds compared with that in Phu Dien ($p>0.05$) (see Table 13). The average survival rate of shrimp in the ponds was 74.6 percent. Yield averaged at 0.9 t/ha, which is quite high for polyculture ponds.

Fish ponds also achieved high growth rates. The average weight of rabbitfish was 208 g per piece. However, rabbitfish in Phu Thuan showed slower growth compared with those in the other ponds. Statistical analysis showed significant differences across the ponds ($p>0.05$) (see Table 14).

Average survival rate of rabbitfish was 88.6 percent and its average yield was 1.38 t/ha. For kinh, average weight was 46.26 g per piece, survival rate was 79.4 percent, and yield was 1.46 t/ha.

**Economic Evaluation of Aquaculture Models**

Preliminary calculations of economic efficiency of aquaculture models (Table 14) showed high profits after 4.5 months of culture. Profit was highest in Phu Tan at VND 121.1 million. This implies that polyculture models are capable of adapting to changing climate conditions in Phu Vang district, and to Thua Thien Hue province in general. Not only did the models bring about economic improvement, they also met the need for diversified species. In addition to traditional species such as rabbitfish and tiger shrimp, kinh proved promising. With its high potential in economic value, it can be a good substitute when shrimp production becomes risky because of environmental pollution and disease outbreaks.

However, being semi-intensive, this farming method requires high initial capital investment. This poses a challenge to many farmers who do not have the financial capability to embark on this venture. Nonetheless, farmers can reduce the density of the species or use extensive farming methods, depending on their investment capacity.

**Table 12. Density, breeding size for stocking, and feed use**

| Species | Density (pieces/m2) | Size (cm) | Feed |
|---|---|---|---|
| Tiger shrimp | 7 | 1-2 | Commercial feeds |
| Rabbitfish | 1 | 4-5 | Commercial feeds and seaweed |
| Kinh | 4 | 2-3 | Commercial feeds and seaweed |

**Table 13. Average weight (AW), survival rate (SR), yield (Y), and productivity (P) of aquaculture model**

| Pond | Tiger shrimp P. monodon | | | | Rabbitfish S. guttatus | | | | Kinh S. canaliculatus | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AW (g/pc) | SR (%) | Y (t) | P (t ha-1) | AW (g/pc) | SR (%) | Y (t) | P (t ha-1) | AW (g/pc) | SR (%) | Y (t) | P (t ha-1) |
| Phu Tan | 17.5a±2.6 | 78 | 0.477 | 0.95 | 169a±3.7 | 89 | 0.75 | 1.50 | 47.8a±1.9 | 81 | 0.77 | 1.54 |
| Thuan An | 17.3a±3.1 | 75 | 0.454 | 0.90 | 162a±2.8 | 86 | 0.70 | 1.40 | 46.6a±3.2 | 83 | 0.77 | 1.54 |
| Phu Thuan | 17.1a±2.4 | 74 | 0.443 | 0.87 | 146b±3.1 | 92 | 0.67 | 1.34 | 44.2a±2.8 | 78 | 0.69 | 1.38 |
| Phu Hai | 17.8a±2.1 | 77 | 0.479 | 0.99 | 164a±2.6 | 84 | 0.69 | 1.38 | 47.4a±3.0 | 79 | 0.75 | 1.50 |
| Phu Dien | 16.6b±2.5 | 69 | 0.401 | 0.82 | 160a±3.4 | 82 | 0.65 | 1.30 | 45.3a±2.4 | 76 | 0.69 | 1.38 |
| Average | 17.26 | 74.6 | 0.451 | 0.90 | 208 | 88.6 | 0.69 | 1.38 | 46.26 | 79.4 | 0.73 | 1.46 |

**Table 14. Economic accounting of the aquaculture model**

| Item (000 VND pond-1) | Phu Tan | Thuan An | Phu Thuan | Phu Hai | Phu Dien |
|---|---|---|---|---|---|
| Total expenditure | | | | | |
| Pond preparation | 4,000 | 4,000 | 4,000 | 4,000 | 4,000 |
| Labor | 21,000 | 21,000 | 21,000 | 21,000 | 21,000 |
| Shrimp breeds | 1,590 | 1,590 | 1,59 | 1,590 | 1,590 |
| Kinh breeds | 6,000 | 6,000 | 6,000 | 6,000 | 6,000 |
| Rabbitfish breeds | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 |
| Feed | 75,820 | 75,820 | 75,820 | 75,820 | 75,820 |
| Lime, minerals, vitamins | 5,000 | 5,000 | 5,000 | 5,000 | 5,000 |
| Electricity and gasoline | 18,000 | 18,000 | 18,000 | 18,000 | 18,000 |
| Others | 15,000 | 15,000 | 15,000 | 15,000 | 15,000 |
| Total cost | 134,410 | 134,410 | 134,410 | 134,410 | 134,410 |
| Total revenue | 255,510 | 249,420 | 234,190 | 248,870 | 225,930 |
| Net income | 121,100 | 115,010 | 99,780 | 114,460 | 91,520 |

Note: USD 1.00 = VND 20,873.2 (2012) (source: https://www.investing.com/currencies/usd-vnd-historical-data)

# DISCUSSION

The impact of climate change on the environment has become a global concern due to the scope and extent of human influence. As reported by Vietnam's Ministry of Natural Resources and Environment (2007), the country is one of the most severely affected. Other agencies also warned about the impacts of climate change and presented possible scenarios for all stakeholders to act on.

Human understanding plays a huge role in reducing the impacts of climate change. Tuyen (2002) has shown how limited the response of people was because of poor understanding about climate change. On the other hand, this study found low educational level of the people in coastal areas of Phu Vang. Up to 79.32 percent of the respondents said they did not know anything about climate change. As a consequence, they suffer from losses due to climate change although 71.42 percent of these households have been engaged in aquaculture for more than 10 years.

Water quality significantly affects aquaculture activities, as shown in the experience of shrimp production in Thua Thien Hue (Tuyen 2002). In recent years, water in the Tam Giang-Cau Hai lagoon has been seriously polluted, mainly because of human activities.

Climate change has direct and indirect impacts on the quality of water resources. Research on the impacts of climate change on water quality of the Mekong River was conducted from 1985 to 2012 (Cuong 2012). Results showed the relationship between meteorological parameters and water quality, especially the relationship between monthly average air temperatures and water temperatures, as well as between meteorological parameters and DO, pH, and total suspended solids. Increased rainfall increases surface flow that subsequently leads to increased concentration of organic compounds in the water, increased concentration of suspended solids dissolved in water, and enhanced organic pollution of water sources. On the other hand, the research has shown that the lagoon of Phu Vang has phenomenal organic pollutants in the rainy season, especially during and after floods. There is increase in the concentration of TDS and high COD levels during the rainy season.

Murdoch, Baron, and Miller (2010) collected data from long-term ecosystem monitoring and research stations in North America. Results of simulations made with interpretive models indicate that changes in climate (precipitation and temperature) can have a significant effect on the quality of surface waters. Changes in water quality during storms, snowmelt, and periods of elevated air temperature or drought can cause conditions that exceed thresholds of ecosystem tolerance, leading to water quality degradation. If warming and changes in available moisture occur, water quality changes will likely first occur during episodes of climate-induced stress and in ecosystems where the factors controlling water quality are sensitive to climate variability. Continued climate stress would increase the frequency with which ecosystem thresholds are exceeded and would thus lead to chronic water quality changes. It was further recommended that management strategies in a warmer climate will therefore be needed based on local ecological thresholds rather than on annual median condition. Changes in land use alter biological, physical, and chemical processes in watersheds and thus significantly alter the quality of adjacent surface waters. These direct human-caused changes complicate the interpretation of water quality changes resulting from changes in climate and can be both mitigated and exacerbated by climate change. It was concluded that a rigorous strategy for integrated, long-term monitoring of the ecological and human factors that control water quality is necessary to differentiate between actual and perceived climate effects and to track the effectiveness of the environmental policies.

This issue was also raised in a study by Tu and Quang (2010) where it was pointed out that extreme weather events such as typhoons and prolonged floods have caused the freshening lagoon phenomenon, a type of ecosystem degradation characteristic of brackish water in the Tam Giang-Cau Hai lagoon. Conditions were created for the growth of bacteria and harmful fungi, endangering aquatic life.

Several methods are currently used to assess water quality, including Geographic Information System (GIS) software applications, which is capable of assembling, storing, manipulating, and displaying geographically referenced information. GIS has been used in aquaculture since the mid-1980s, and in the early 1990s.

In this research, GIS was applied to analyze environmental data over time and through a special application, localize and evaluate water quality in the lagoon area of Phu Vang district. Results were analyzed to identify environmental parameters and their volatility in the study area. This result also validated the findings of Hop et al. (2007) that climate change has negative impact on water quality for aquaculture, directly affecting aquaculture activities, reducing productivity and overall aquaculture production in Phu Vang. This study confirms that aquaculture areas decreased over time, water pollution and diseases occurred often, ecological structure and animal breeds and crop farming changed, and productivity and yield decreased.

Tu and Quang (2010) have shown that extreme weather events such as prolonged drought in the dry season and early flooding led to heavy losses in the aquaculture industry in Thua Thien Hue in recent years. In 2010, total shrimp production has decreased by half compared with 2004; the main reason is prolonged heat wave that also led to disease outbreaks. Additionally, when the temperature rises too high, animals reared in the ponds may die or grow slowly or eat less. The current investigation concluded that severe weather has reduced aquaculture productivity in Phu Vang compared with previous performance between 2003 and 2004 (Table 10). Tuong et al. (2008) also stated that habitat degradation associated with extreme changes in weather (particularly increases in air temperature and prolonged heat) and disease outbreaks occurred simultaneously in many places in Phu Vang district. Tiger shrimp kill consequently decreased production efficiency, thereby greatly decreasing the income of farmers. As a result, many farmers changed species and farming methods to suit the current weather conditions. Some moved away to other jobs and aquaculture area in the whole district was significantly reduced (Tuong et al. 2008).

Not only did climate change have a direct impact on aquaculture activities; it also changed the ecosystem characteristics of Thua Thien Hue lagoon. Weather phenomena such as sea level rise have increased the risk of saltwater intrusion in estuaries such as Huong, Bu Lu, Dai Giang, and Truoi rivers. Seawater influx into the lagoon has also increased, leading to much higher overall salinity levels in the lagoon. Therefore, the Tam Giang-Cau Hai lagoon faces the risk of being degraded, with brackish water fishery resources declining. The most notable of these is the sharp decline in fish species of considerable economic value, such as the rabbitfish, kinh, mullet, and grouper (Quyen 2010).

Numerous studies worldwide have confirmed the preceding findings. According to IPCC (2007), changes in rainfall will cause a spectrum of changes in water availability, ranging from droughts and shortages to floods, and will reduce water quality. Salinization of groundwater supplies and the movement of saline water further upstream in rivers caused by rising sea levels will threaten inland freshwater aquaculture. Increased runoff, bringing in nutrients from sewage or agricultural fertilizers, may cause algal blooms that will in turn lead to reduced levels of dissolved oxygen and fish-kill (Diersing 2009). Rising temperatures similarly reduce levels of dissolved oxygen and increase the metabolic rates of fish, leading to increases in fish deaths, declines in production, or increases in feed requirements while also increasing the risk and spread of disease (FAO 2008).

Coastal aquaculture will be exposed to major economic losses from extreme weather events and red tides, the frequency and severity of which are likely to increase. Climatic changes could increase physiological stress on cultured stock. This would not only affect productivity but also increase vulnerability to diseases and, in turn, impose higher risks and reduce returns to farmers (FAO 2008).

Extreme weather events could result in escapes of farmed stock and contribute to reductions in genetic diversity of the wild stock, affecting biodiversity more widely. Therefore, aquaculture will face many difficulties due to greatly reduced stock. As Bell et al. (2009) has stated, climate change has caused damage to aquaculture, including billions of dollars every year in India and other countries in Asia.

A review of the impact on the economic climate in Vietnam estimated that each year, climate change impacts 5 percent of Vietnam's GDP, equivalent to USD 15 billion (MNRE 2007). In particular, due to rising seas, Vietnam loses USD 4 billion a year, and USD 8 billion in climate change costs of labor productivity losses amount to around USD 8 billion. The fishing industry loses around USD 1.5 billion, while agriculture loses USD 0.5 billion. Losses from floods and landslides amount to USD 200 million, and the costs incurred to cool when the temperature rises is USD 150 million, and 650 million for aquaculture and livestock.

To mitigate the impacts of climate change, research was done on aquaculture to adapt to climate change in Phu Vang district, Thua Thien Hue province. Binh, Chat, and Thuy (2010) have assessed polyculture models using three species (rabbitfish, tiger shrimp, and tilapia) and improved extensive farming methods in Huong Phong commune, Huong Tra district, Thua Thien Hue province. This resulted in profits of VND 67 million for every half-hectare pond area. Phi (2011) developed polyculture models using rabbitfish, mullet, and black tiger shrimp in the same commune with profits of VND 140 million per ha. This study proposed a polyculture model that involves rabbitfish, kinh, and black tiger shrimp under semi-intensive farming. Although the initial capital outlay was relatively high, profit margins were also significantly increased to more than VND 200 million per ha (see Table 13).

# SUMMARY AND CONCLUSIONS

Climate change is a major problem that concerns humanity. The extent and scope of the impact of climate change is wide, affecting not only the physical environment but also the livelihood of the people. The negative effects of climate change on humans have been predicted and Vietnam is one of five countries identified to be affected most severely by climate change and sea level rise (ADB 2010). Therefore, climate change needs to be considered in terms of strategies and plans for the development of long-term and short-term goals of each locality in Vietnam.

As a coastal district, Phu Vang has always suffered heavy losses from climate change. Over time, it was found out that weather conditions and climate in Phu Vang showed complicated movements and abnormal changes such as droughts and prolonged heat waves often occurring during the dry season from May to August every year. Meanwhile, cold weather lasted longer during rainy season (October to December). Floods and typhoons have occurred with stronger intensities, and tide amplitude has changed drastically. All these have had significant impacts on agricultural activities in general and on aquaculture activities in particular. Aquaculture is considered as one of the most vulnerable sectors affected by climate change.

The negative impact of climate change on aquaculture activities in Phu Vang district include decreasing aquaculture area over time, changing structure of animal breeding and crop season, and reduced yield and productivity. These make people's lives more difficult. Many households engaged in aquaculture have converted from intensive culture to extensive culture; others left their ponds and moved to other jobs, resulting in significant changes in income and in their lives.

The people have a limited understanding of climate change, thereby affecting their ability to respond to changes in their environment. They have always suffered heavy losses due to unpreparedness to mitigate the effects of climate change.

In addition, this study also noted the negative impacts of climate change on water quality for aquaculture purposes in Phu Vang district. Rising temperatures and prolonged droughts, prolonged rainfall, flooding, and salinization have changed the quality of water, greatly contributing to reduced productivity and yield. This meant lower income of the people.

In spite of attention given by various levels of government, the efforts of the community to respond to disasters have been minimal. Effective solutions in response to climate change are yet to be found. It is therefore imperative to address the need for policies that would integrate adaptation measures into the overall development plan of the fishery sector. This would be crucial in helping localities respond better to climate change in order to ensure sustainable development. The people must always have a proactive mindset and apply their own experiences to minimize the threat posed by climate change.

In addition, polyculture models using rabbitfish, kinh, and tiger black shrimp have brought high economic returns. This model can thus be replicated in various communes in Phu Vang district.

# POLICY IMPLICATIONS AND RECOMMENDATIONS

Based on the results of this study, a number of solutions are recommended to achieve an adequate and timely response to climate change in aquaculture in Phu Vang district, Thua Thien Hue province. With the current climate scenarios, approaches in the past are no longer applicable. There is a need for measures to respond on time and to prepare for long-term changes in weather. Thus, to mitigate damage caused by climate change and to facilitate sustainable economic opportunities for people in the coastal lagoons of Thua Thien Hue province, particularly Phu Vang district, a number of measures are proposed.

### Short-term Solutions

1. Strengthen the propagation and dissemination of knowledge and information; raise the awareness of government officials and local people about climate change and its impact, as well as about methods and strategies for adaptation and mitigation.
2. Encourage farmers to strictly follow regulations and decrees related to ensuring the sustainability of aquaculture. Specifically, compliance with schedule, stocking requirements, and quality assurance protocols must be enforced.
3. Maintain and expand the area of polyculture, increase species diversity, and encourage domestication and introduction of new species that can easily adapt to changes in the water environment.
    - Prioritize native species that have been cultured and that have adapted well, and identify hybrid species and polyculture species capable of being cultivated together. These species should have good economic value and high market demand.
    - Engage in biotechnology research to develop new species better adapted to the changing environment.

### Long-term Solutions

1. Conduct marketing research to secure good markets for aquaculture products, thereby giving farmers economic security.
2. Speed up the implementation of the government's support policies to mitigate the damage caused by natural disasters and epidemics in aquaculture.
3. Identify and develop suitable aquaculture areas and examine suitable culture locations to avoid the negative effects of extreme weather events. Overall planning and detailed execution must be done for each aquaculture area.
4. Train a cadre of specialists on veterinary aquaculture; officials must be able to analyze the measures proposed to respond to climate change in accordance with specific conditions of the locality.
5. Build an early warning system and weather forecasts to prepare the community for the occurrence of unusual weather phenomena.

### Technical Solutions

1. Develop the needed infrastructure for semi-intensive and intensive culture areas; set up a wastewater treatment system before any used water is discharged into the environment.
2. Build permanent ponds and embankments systematically for flood prevention.
3. Increase the water level to not less than 1 m in high embankment ponds; shallow water allows environmental factors to be volatile, especially in the dry season.
4. Plant trees along breakwaters and coasts. Planting grasses would control erosion; anti-erosion devices must also be constructed.
5. Build fish cages that are resistant to strong waves; identify culture species that can adapt to the climate of each region to minimize the impacts of weather changes.

# REFERENCES


ADB (Asian Development Bank). 2010. Enhancing Human Security, the Environment and Disaster Management in Hue, Vietnam. Environmental Technology Resources Handbooks. ADB, Philippines.

Aguilar-Manjarrez, J. and L.G. Ross. 1995. Geographic Information System (GIS) Environmental Models for Aquaculture Development in Sinaloa State, Mexico. Institute of Aquaculture, University of Stirling, Scotland, UK.

American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF). 1995. *Standard Methods for the Examination of Water and Wastewater. 19th Edition.* APHA, Washington, D.C.

An, L.V., and H.D.T. Hoang. 2007. Climate Change Effects in Tam Giang-Cau Hai lagoon. IMOLA Project, Thua Thien Hue, Vietnam.

Bell, J., M. Batty, A. Ganachaud, P. Gehrke, A.J. Hobday, O. Hoegh Guldberg, J.E. Johnson, R. Le Borgne, P. Lehodey, J.M. Lough, T. Pickering, M.S. Pratchett, M.J. Sheaves, and M. Waycott. 2009. Preliminary Assessment of the Effects of Climate Change on Fisheries and Aquaculture in the Pacific. Asian Development Bank, Manila, Philippines.

Binh, M.N., T.T. Chat, and N.T.T. Thuy. 2010. "Climate change and climate variability in Thua Thien Hue province: Initially studied the effects of climate change to aquaculture." *Journal of Hue Science* (in Vietnamese), pp. 16–29.

Cuong, T.T. 2012. Scenarios of climate change and sea level rise for Vietnam. Hand Book. Ministry of Environment and Resources, Vietnam.

DARD (Department of Agriculture and Rural Development of Phu Vang District). 2012. Aquaculture Situation in Phu Vang District. Final report (in Vietnamese). Annual Report of the District, Phu Vang, Thua Thien Hue, Vietnam.

Delpla, I., A.V. Jung, E. Baures, M. Clement, and O. Thomas. 2009. "Impacts of Climate Change on Surface Water Quality in Relation to Drinking Water Production." *Environment International* 35(8): 1225–1233.

Diersing, N. 2009. Water Quality: Frequently Asked Questions. Florida Keys National Marine Sanctuary. http://floridakeys.noaa.gov/scisummaries/wqfaq.pdf

FAO (Food and Agriculture Organization of the United Nations). 2008. "Climate Change for Fisheries and Aquaculture." Technical background document from the expert consultation. 7–9 April 2008. FAO. Rome, Italy.

———. 2012. 2010 Fishery and Aquatic Statistics. Rome, Italy. http://www.fao.org/docrep/015/ba0058t/ba0058t.pdf

Hop, N.V., N.X. Khoa, T.V. Nghi, and P.H. Viet. 2007. Water quality assessment in the Tam Giang–Cau Hai lagoon. IMOLA project final report. pp. 213.

Hop, N.V., N.X. Khoa, and T.V. Nghi. 2010. Surface Water Quality in Thua Thien Hue Province, The 4th General Seminar of the Core University Program: Environmental Science and Technology for Sustainable Development, Osaka University, Japan, pp. 79–88.

IPCC (Intergovernmental Panel on Climate Change). 2007. Fourth Assessment Report—Climate Change 2007: Synthesis Report. Valencia, Spain, pp. 12–17.

Lang, T.T. 2010. Research on Water Quality Index to Evaluate Water Quality Partitions in Hau River, Vietnam. *Journal of Science*. Can Tho University. pp. 34–42.

Ministry of Agriculture and Rural Development. 2010. Circular No. 44/2010/TT-BNNPTNT. Vietnam Standards for the Quality of Water for Shrimp Farming. Vietnam (in Vietnamese).

MNRE (Ministry of Natural Resources and Environment). 2007. National Target Program to Respond to Climate Change. National Report, Hanoi, Vietnam.

———. 2008. National Technical Regulation on Coastal Water Quality. Vietnam.

Murdoch, P.S., J.S. Baron, and T.L. Miller. 2010. "Potential Effects of Climate Change on Surface-Water Quality in North America." *Journal of the American Water Resources Association* 36(2): 347–366.

Ngoan, L.D., and N.D.Q. Tram. 2010. Mitigation of Natural Disasters and Response to Climate Change in Aquaculture in Thua Thien Hue Province. FSPS Project Report (in Vietnamese).

Nicholls, R.J., P.P. Wong, V.R. Burkett, and J.O. Codignotto. 2007. *Coastal Systems and Low-lying Areas.* Cambridge University Press, Cambridge, UK, pp. 315–356.

Phi, C.N. 2011. Economic Efficiency of Polyculture in Huong Phong Commune, Huong Tra District, Thua Thien Hue Province. The Summary Record of the National Workshop in Thua Thien Hue, pp. 113–135 (in Vietnamese).

Phu Vang District Report. 2013. Report on Aquaculture Status of Phu Vang District in the Period of 2008–2012 (in Vietnamese).

Quyen, C.L. 2010. Climate Change is Causing a Great Impact on Fisheries in the Coastal Lagoon of Vietnam. *Journal of Economics and Environment.* Institute of Economics and Planning Fisheries, Hanoi, Vietnam.

Roessig, J.M., C.M. Woodley, J.J. Cech, and L.J. Hansen. 2004. “Effects of Global Climate Change on Marine and Estuarine Fishes and Fisheries." *Reviews in Fish Biology and Fisheries.* 14(2): 251–275.

Suu, L.T.T., and N.X. Binh. 2006. Livelihood, Vulnerability and Local Adaptation Strategies to Natural Disasters in Huong River Basin. The ADAPTS Programme in Vietnam, Synthesis Reports. Hanoi, Vietnam.

Suu, L.T.T, P.T. Dieu, P. Bubeck, and A. Liekedouma. 2010. Community-based Adaptation Strategies for Enhancing Resilience to Climate Change in the Huong River Basin, Thua Thien Hue province, Vietnam. The ADAPTS Programme in Vietnam, Synthesis Reports. Hanoi, Vietnam.

Thanh, T.K. 2011. Flood in Thua Thien Hue Province and Control Measures. Department of Agriculture and Rural Development, Thua Thien Hue, Vietnam.

TTHSO (Thua Thien Hue Statistical Office). 2012. Thua Thien Hue Statistical Yearbook. Hue, Vietnam: Thua Thien Hue Statistical Office.

Trap, N. 2006. Vulnerability of Fishing Communities in Vietnam: An Exploration of the Scope to Adapt to Environmental Change. Thesis report. Vrije Universiteit, Amsterdam, Netherlands, pp. 45 http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.462.787&rep=rep1&type=pdf

Tuong, L.N., T.M. Kien, T. Thuc, and T. Quynh. 2008. Climate Change Impacts in Huong River Basin and Adaptation in its Coastal District PhuVang, Thua Thien Hue Province. Final Report, National Climate Change Program. Hanoi, Vietnam.

Tu, T.T., and T.H. Quang. 2010. Impacts of Climate Change on Aquaculture Field in Thua Thien Hue. Vietnam: Institute for Resources, Environment and Biotechnology, Hue University.

Thuy, N.N., and B.D. Khuoc. 2012. Climate characteristics of Vietnam. *Journal of Environmental Science.* Hanoi, Vietnam (in Vietnamese).

Tuyen, T.V. 2002. The Aquaculture Expansion in Tam Giang Lagoon, Vietnam and its Management Challenges. In Communities in Southeast Asia: Challenges and Responses, eds. H. Lansdowne, P. Dearden and W. Neilson, 12–18. Canada: University of Victoria.

EDITORIAL STAFF

**Advisers:**
Gil C. Saguiguit, Jr.
Maria Celeste H. Cadiz
Bessie M. Burgos

**Managing Editor:**
Mariliza V. Ticsay

**Production Coordinators:**
Carmen Nyhria G. Rogel
Monalinda B. Cadiz

**Production Assistant:**
Arlene A. Nadres

For more information about SEARCA publications, please contact:

Knowledge Resources Unit
Knowledge Management Department
SEARCA, College
Los Baños, Laguna 4031 Philippines
Tel. Nos. (63-2) 657-1300 to 09
(63-49) 536-2290, 554-9330 to 39
536-2365 to 67 local 3201
Fax: (63-49) 536-7097 (Attn: KRU)
Email: publications@searca.org
or visit www.searca.org

The Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) is one of the 21 regional centers of excellence of the Southeast Asian Ministers of Education Organization (SEAMEO). Founded on 27 November 1966, SEARCA is mandated to strengthen institutional capacities in agricultural and rural development in Southeast Asia through graduate scholarship, research and development, and knowledge management. It serves the 11 SEAMEO member countries, namely: Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor Leste, and Vietnam. SEARCA is hosted by the Government of the Philippines on the campus of the University of the Philippines Los Baños (UPLB) in Laguna, Philippines. It is supported by donations from SEAMEO member and associate member states, other governments, and various international donor agencies.

About the Cover: The cover features a Growth Monument that stands proud on the rolling front lawn of the SEARCA Building. This monument, consisting of 11 stylized human figures linked internally, represents the 11 countries that support SEARCA. The internal linkages clearly concretize the contention that no institution, no action, in fact, nothing at all becomes, without man as the animating force. Specifically, it is attuned to the aim of SEARCA for capacity building as a precondition to agricultural growth.

ISSN-1908-6164