MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT

**VIET NAM INSTITUTE OF METEOROLOGY, HYDROLOGY AND CLIMATE CHANGE**

**NGUYEN XUAN TRINH**

# STUDY ON DELIMITATING AQUA-ECOLOGICAL ZONES IN THE MEKONG DELTA REGION UNDER CONDITIONS OF CLIMATE CHANGE

**Field of study: Natural Resources and Environment Management**

**Code : 62850101**

SUMMARY OF DISSERTATION

ENVIRONMENTAL CONTROL AND MANAGEMENT

**HA NOI – 2018**

Fulfilled dissertation at:

**Viet Nam Institute of Meteorology, Hydrology and Climate Change**

**Instructors**:

1. As.Prof. Doan Ha Phong
2. As.Prof. Le Xuan Tuan

Criticizer 1: ……………………………….
Criticizer 2:…………………..……..…….
Criticizer 3: ………………………………..

The dissertation will be defenced at Viet Nam Institute of Meteorology, Hydrology and Climate Change

Hour Day Month year 2018

The dissertation is available at:

- National Library of Viet Nam
- Library of Viet Nam Institute of Meteorology, Hydrology and Climate Change

## INTRODUCTION

### 1. Rationale

Mekong River Delta (MRD) is a key area for agriculture and fisheries development of Vietnam, in which fisheries accounts for approximately 80% of the total export value of aquaculture products. However, this region is also considered one of the three most vulnerable regions in the world due to extreme weather and climate change (CC). Disasters and extreme events have shown a sharp increase and continued to act as an barrier to the goal of sustainable development, poverty reduction, food security and especially, as a threat of human livelihoods. These challenges require a sensible solution to conserve the ecological structure and improve production efficiency in the context ofCC condition.

Study of ecological zoning (EZ) provides a scientific foundation for the formation of production areas based on the structural similarity of natural, environmental, ecological, and ecological characteristics as well as manufacturing sector. Although a number of studies related to aquaculture, ecology and CC have been conducted in the MRD, some points in scientific basis have been unclear. Particularly, the changes of aquaculture ecological zones (aqua-ecological zone, AEZ) in space and chronological order due to the impacts of CC have not been studied yet.

Due to some issues mentioned above, the thesis titled "*Study on aqua-ecological zoning inMRD in the context of CC*" is implemented to contribute more to the scientific basis and propose solutions to reorganize production activities in line with ecological changes of water resources for managing and planning aquaculture to adapt to adverse impacts of CC in the MRD region.

## 2. Objectives

- To establish theory and practice of AEZ development in the MRD
- To delimitate ecological zonesunder the CC in MRD for aquaculture development
- To propose solutions for managing aquaculture by spatial zones under the CC in MRD

## 3. Subject and Scope

- *Subject*: Natural ecology, aquaculture production, elements related to CC and AEZ
- *Scope*: 13 provinces in MRD.

## 4. Argument of the dissertation:

- CC creates opportunities for the expansion of inland aquaculture production in the MRD and AEZ, which contributes to the restructure of agricultural production in the context ofCC in 2030 and 2050.
- Aquaculture production models in rotation/combination with agriculture in flood and salinity areas are climate-smart models.

## 5. The scientific and practical significance of the dissertation

### 5.1 Scientific significance

- The findings of the study will act as scientific arguments and basis for AEZ.

- Identify, clarify the nature of impact and integrate elements of CC to define the spatial distribution of AEZ according to CC scenario for the MRD.

**5.2 Practical significance**

- The findings have practical implications for managers in developing strategies for aquaculture development in provincesof the MRD.

- The findings initially provide an important basis for the development of production restructuringmodels adapting to the CC in the MRD.

## 6. Contribution of the dissertation

- Findings of the study have established scientific foundation for aqua-ecological zoning in MRD under the impacts of CC.

- Integrating aqua-ecological zoning into the spatial planning for the MRDas well as proposing climate-smart aquaculture models.

## 7. Structure of the dissertation

Chapter 1: Overview of the research issue

Chapter 2: Approach and methodology

Chapter 3: Findings and discussion

Conclusions and recommendations

List of the author’s worksralted to the study

Reference

Annexes

# CHAPTER 2
# APPROACH AND METHODOLOGY

## 2.1 Approach

The factors ① and ② are the inputs of the simulation model that cause ecological variation in water resources ③. At ③, ecological zoning is based on the characteristics of water resources classified into two levels. Products of ③ combined with features of climate-smart aquaculture models ④ are a basis for AEZ⑤.

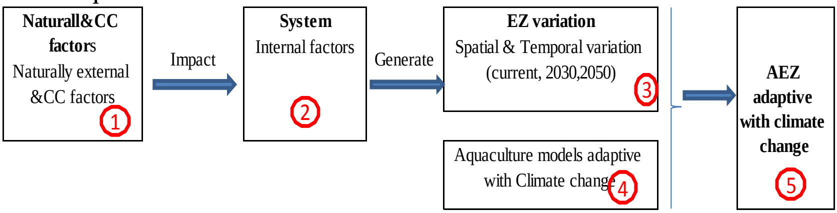



Figure 2.1: Approach of AEZin climate change condition

### *a. AEZin climate change condition*

Figure 2.1 describes the approach to achieve research objectives. Specifically, ① describes the peripheral factors for defining precipitation in the region and the entire MRD and impacts of tides.② desribes intrinsic factors identified as terrain, soils, hydrology (rivers) ... combined with exogenous factors that create variation in water resource's ecology in aquaculture ③. Rotated and combined aquaculture models ④ adapting to CC are attached to ③ to form ⑤

*Current AEZ*: using input data ① the year representing the average flow (2004)

*AEZ under the impact of CC in 2030, 2050*: Using factors such as rainfall, rising sea level of national scenarios and IPCC scenarios for the whole region during 2030,2050 to change the input of ①,the results will create AEZ under the impact of CC⑤ for the corresponding periods of 2030, 2050

***b. AEZ under the impact of extreme events and climate change (applicable** to inland region)*

- *AEZ due to current extreme events and CC*

Step 1: Use figures of the years with drought and floods (2000, 1998)

Step 2: Compare the variation in the regions with drought, floods with the scenario of the year with an average flow (2004)

- *AEZ due to extreme events &CC in 2030, 2050*

Step 1: Build the model of scenario for areas with ecological variation due to extreme events such as drought, floods in 2030, 2050.

Step 2: Compare variations of geographical areas in the scenario with droughts, floods with the scenario of the year featuring corresponding average flow

## 2.2.Methodology

*Datastandardization*: (1) Standardization of coordinate systems; (2) standardization of format; (3) Standardization of resolution; (4) Standardization of geometry

*Data for EZ*: Data for EZ are collected and built: (1) Wetland and salt intrusion measurements (figures in 1998, 2000 and 2004); (2) A map of the current status of aquaculture (based on a 1 / 25,000 land use map, combined with local surveys and support of Landsat 8; (3) Terrain data (Digital elevation model DEM with resolution of 10m); (4) soil maps; (5) terrain data for seabed (used in EZ in the intertidal area); (6) tide data (2 measuring stations: Binh Dai - Ben

Tre measurement station representing the tide of the East Sea, Rach Gia measurement station representing the tidal movement of the West Sea) (7) other layers of information (extracted from layers of information of topographic maps, land use ... as inputs for data analysis)

*Methods*: (1) Modeling Approach (VRSAP Modeling of Flow Simulation for Spatial Data (Map) of Salt intrusion and Floods in 1998, 2000 and 2004 Scenarios and Scenarios for Water Resources Changes in 2030, 2050 for the three corresponding scenarios mentioned above; (2) survey methods (add and update information); (3) Remote sensing and GIS analysis methods (used in analysis, integration of maps with weights; (5) Topography analysis method (building seabed topography) (6) Tide analysis method

### 2.2.2. Methods of zoning

#### 2.2.2.1 AEZ under different climate conditions

***a. Methods of ecological zoning in inland areas***

The zoning method is done according to levels and implemented through 3 levels:

Table 3.2: Criteria for defining sub-zone of ecology level 1

| No | Ecology level 1 | Criteria of saltwater intrusion |
|---|---|---|
| 1 | Brackish-water of AEZ | Saltwater intrusion all year round |
| 2 | Transitional AEZ | Saltwater intrusion in dry seasons 0‰ |
| 3 | Fresh water of AEZ | No saltwater intrusion all year round |

- *Ecological zoning level 1*: Show the basic ecological areas (saltwater, brackish water, fresh water) based on water sources' ecology.

- *Ecological zoning level 2*: Show in detail of the ecological areas level 1. Spefically, the criteria of water source's dynamics in space and over timeare presented in detail for zoning properly for aquaculture models adapted to CC.

- *Ecological zoning level 3* - Detailed zoning: Defining criteria: (i) Water sources advantage： Weight 0.35; (ii) security factor: weight 0.3; (iii) soil factor: weight 0.15; (iv) Topographic features: Weight 0.2. Classification and rating of criteria: The goals of each criterion are classified into 4 grades corresponding to points from 1 - 4. In which: 1. Not suitable; 2. Fairly suitable; 3. Moderately suitable; 4. Very suitable

- *Integrating score of each criterion*

Use a formula to determine the score for the appropriate rating map on each pixel: $S = \Sigma W_i * X_i$

Where: $S_i$: appropriateness index; $W_i$: The comprehensive weight of standard i. Xi: Value (points) of standard i

All pixels have a value of 1-4. Using the appropriate hierarchy from 1-4 above will identify suitable areas on the map

Table 3.3: Criteria for inland AEZ - level 2

| | Criteria | | | | |
|---|---|---|---|---|---|
| No. | AEZ level 1 | Salinity intrusion | Flooding depth | Duration of flood | AEZ level 2 |
| 1 | Brackish water aquaculture ecology | During the year | No or little impact | No | Brackish water aquaculture subzone |
| 2 | Aquaculture transition ecology | In dry season >4‰ | No or little impact | No | Seasonal transition aquaculture ecology |
| 3 | | In dry season 0–4‰ | No or little impact | No | Fresh water aquaculture ecology – salt prevention |
| 4 | | In dry season >0‰ | Flooding ≥ 1 m | ≥90 days | Flood and salt water zone |
| 5 | Freshwater aquaculture ecology | No salinity during the year | No or flooding ≤1 m | No or <90 days | Fresh water aquaculture ecology – moderately inundated flood |
| 6 | | No salinity during the year | Flooding 1–2 m | ≥90 days | Fresh water aquaculture ecology – semi-inundated flood |
| 7 | | No salinity during the year | ≥2 m | ≥120 days | Fresh water aquaculture ecology – inundated flood |

### *b. Method of zoning sea and tidal flat areas*

Basis for basic ecological zoning - Level 1 based on national marine law, marine space planning; Wetlands classification of the RAMSA Convention.

based on: (1) typical features of aquaculture at sea and in tidal flats; (2) characteristics of tides; (3) topography of seabed and tidal flats. (Table 3.10)

Table 3.10: Criteria for classification of ecological sub-zone 1 and 2

| | Criteria | Level 1 | Criteria | Level 2 |
|---|---|---|---|---|
| Marine & tidal flats Ecology | Depth of seabed < -6m | Marine Ecology sea areas <-6m | Distance to island >1km | Marine Ecology for fishery capture |
| | | | Distance to island <1km. | Marine aquaculture |
| | Depth from (-6m) to the lowest tidal boundary | Daily tidal wetland Ecology | Depth from -6m to -2m. | Marine Ecology for fishery capture in coastal areas. |
| | From the lowest tidal to highest tide boundary | | | Capture fisheries in tidal flats |
| | | | -From -0.5 to +0.25m (Eaten area<br>-From -0.2 to +0.1m (West Sea) | Aquaculture in tidal flats |

### **2.2.2.2.** AEZ in extreme events and climate changeconditions*(method only applicable to inland area)*

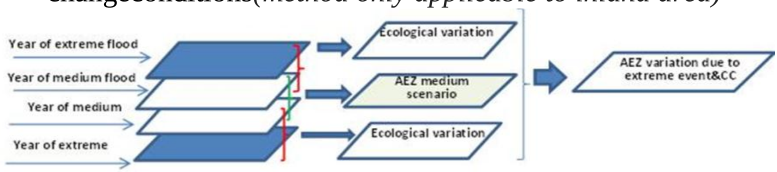



Figure 2.4: Methods of AEZ in extreme events &CC

Extreme events for aquaculture are considered dynamics in water sources of abnormal years (increasing dynamics and decreasing dynamics) compared to years of average flows; combined with the average scenario due to the impact of CC

Salinity uses saltwater intrusion scenario of the year with low flow (1998) compared to the year with an average flow (2004).

Flood extremes use a flood scenario of the year with high flow (2000) compared to the year with an average flow (2004)

# CHAPTER 3
# RESULTS AND DISCUSSION

## 3.1 Establishing scientific foundation

### 3.1.1 Defining the approach

*Ecological approach:* (1)Apply hierarchical approach to preserve the characteristics as well as keep spatial and production zoning far from destroying the structure of natural ecology; (2) Study the spatial structure and the volatility over time.

*Approach to natural elements:* approach to natural peripheral and intrinsic factors to determine the nature of the impact of CC that cause dynamics  in aqua-ecological zones.

*Approach to aquaculture:* Access to aquaculture production (seasons, production models, development orientation of the sector, interdisciplinary, aquaculture production structure at present and in the future .etc.) This will ensure compatibility between aquaculture areas in ecological areas.

*Approach to the impact of CC:* Access to peripheral factors caused by CC in combination with intrinsic factors that cause the dynamics in water source's ecology and affect future aquaculture production.

### 3.1.2. Principles of AEZ under climate change condition

- Principle 1: To be consistent with the development objectives of the sector, multidisciplinary and region.

- Principle 2: Consideration of the function of ecological zones.

- Principle 3: Aqua-ecological zoning is based on the appropriate balance between ecological characteristics and characteristics of aquaculture.

### 3.1.3. Identify and select criteria

- *Selection of timeframe and space for criteria*: The criteria for selecting aqua-ecological zoning must be stable, which is at least 3 months for internal raising and 12 months for mollusc at tide flats.
- *Identification of indicators for criteria:* Indicators for criteria must reflect certain characteristics in accordance with the zoning objectives and ecological characteristics of the aquaculture objects.
- *Integration of CC scenarios in the development of criteria*: Based on the meteorological and hydrological elements of the national CC scenarios as a basis for developing scenarios of space distribution in high resolution of ecological dynamics according to the timelines.

## 3.2 Results of AEZin climate change condition in MRD

## 3.2.1. AEZ under the impact of climate change

### *3.2.1.1 Marine and tidal flats ecological zoning*

Table 3.13: Area (ha) of suitable areas for marine and tidal flats aquaculture development

| | Ecological zones | **Easten areas** | | | | **Westen area** | |
|---|---|---|---|---|---|---|---|
| | | Current | 2030 | 2050 | Current | 2030 | 2050 |
| 1 | Tidal flat aquaculture | 41857 | 32312 | 104 | 4223 | 95 | 0 |
| 2 | Marine aquaculture | | | | | 9274 | |

- *Marine ecological zones*: These are classified into: (i) marine areas with a depth of over 6m; (ii) Marine aquaculture is mainly located on the islands of Kien Giang Province; (iii) The tidal inundated ecoregion regularly has a depth of from 2m to 6m (-2m is considered the lowest tidal boundary)
- *Ecological zone of tidal flats* is divided into (i) from -2m to 0.5m; and (ii) suitable with aquaculture in tidal flats

The results of Table 3.13 show that with the sea level rise of 17 cm by 2030 and 30 cm by 2050 the potential area for developing aquaculture at tidal flats can be significantly reduced. By 2050, the South China Sea only has 204 appropriate hectares; the West Sea will no longer be suitable for aquaculture development in the tidal flats. The reduction of suitable area for tidal aquaculture is due to the impact of sea level rise causing the high tide level to reduce the drying time.

A comprehensive map of marine eco-regions is shown in Figure 3.2; 3.3 and 3.4. The map shows 5 sub-ecozones level 2 are integrated in 3 sub-ecozones level 1

### *3.2.1.2 AEZof Inland area*

#### *a. Results of AEZ level 1*

Level 1 sub-ecozone represents the characteristics of water source's ecology in space and chronological order, including: (i) freshwater ecology; (ii) seasonal ecoregions; (iii) brackish water ecoregion

Specifically: Total area of saltwater intrusion accounts for 38% of the total area in current scenario, 51% of the total area of the 2030 scenario and 53% of the total area under the 2050 scenario.

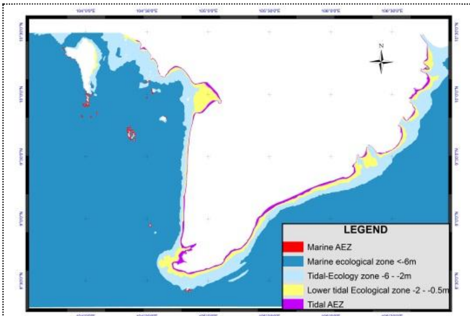



Figure 3.7: Current AEZ of marine and

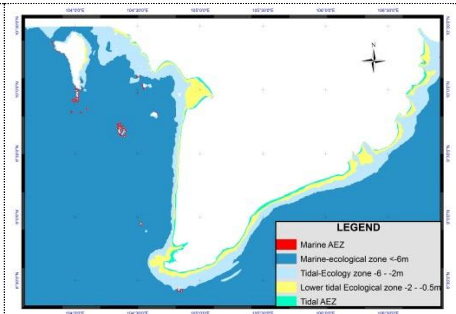



Figure 3.8: AEZ of marine and tidal

tidal flat area

flat areain 2030

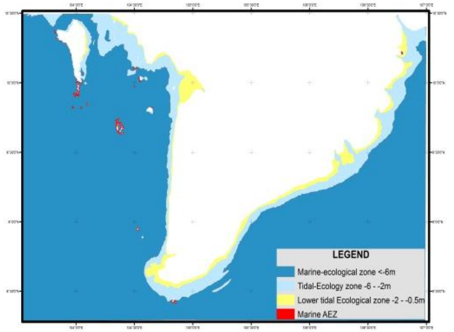



Figure 3.9: AEZ of marine and tidal flatareain 2050

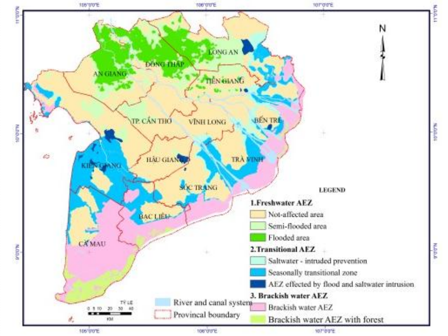



Figure 3.10: Current AEZ of inland area level 2

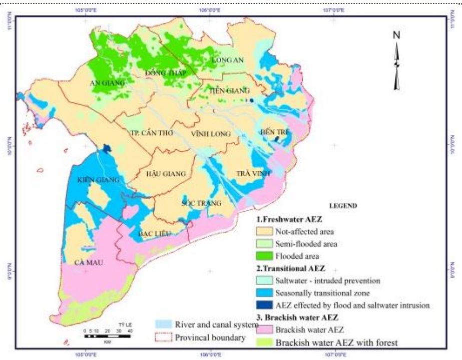
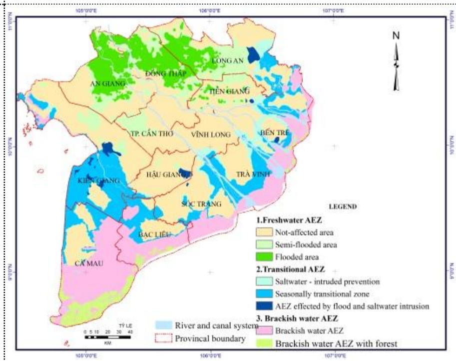



Figure 3.11: AEZ of inland area level 2 in 2030




Hình 3.12: AEZ of inland area level 2in 2050

The area of the freshwater ecozone (level 1) has continuously decreased from 61.8% in the current scenario, 49.4% in the 2030 scenario and 47.2% in the 2050 scenario.

The declined area is mainly of the zone which is only slightly affected by flood. Because the coverage of floodplain and flood area will continue to increase in the future according to CC scenario.

Specifically: Total area of saltwater intrusion accounts for 38% of the total area in current scenario, 51% of the total area of the 2030 scenario and 53% of the total area under the 2050 scenario.

The area of the freshwater ecozone (level 1) has continuously decreased from 61.8% in the current scenario, 49.4% in the 2030 scenario and 47.2% in the 2050 scenario. The declined area is mainly of the zone which is only slightly affected by flood. Because the coverage of floodplain and flood area will continue to increase in the future according to CC scenario.

*b. Targeted AEZ - Level 2*

Three sub-ecoregions of level 1 are divided into 8 sub-ecoregions level 2 as shown in Figure 3.5 (for the present), Figure 3.6 (for the year 2030), Figure 3.7 (for the year 2050). Statistics of ecological zones on the map is shown in Table 3.14.

Specifically:

- The salinity prevention zone has increased sharply in the 2030s (from 6.2% of current scenario, to 16.8% in 2030 and 17.1% in 2050). The main reason for the increase in saltwater intrusion in the 2030 period is due to high altitude (which means the topographic dynamics <20 cm occupy a largest part).

- The ecological zones affected by floods and saltwater intrusion are created due to flood-affected or semi-flooded areas in rainy seasons and saltwater intrusion in dry seasons. The area of this ecoregion is also increasing from 0.01% of the current scenario, 0.2% of the 2030 scenario and 1% of the 2050 scenario.

Table 3.14: Area (ha) of inland AEZ according to scenario

| No | AEZ level 1 | AEZ level 2 | Areas of AEZ variation | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Current** | **%** | **2030** | **%** | **2050** | **%** |
| 1 | **Freshwater AEZ** | Not-affected area | 1923788 | 47.9 | 1324766 | 33.0 | 1124673 | 28.0 |
| | | Semi-flooded area | 272375 | 6.8 | 340573 | 8.5 | 407870 | 10.2 |
| | | Flooded area | 284507 | 7.1 | 320151 | 8.0 | 362701 | 9.0 |
| | | **Total areas** | **2480670** | **61.8** | **1985489** | **49.4** | **1895244** | **47.2** |
| 2 | **Transitional AEZ** | Saltwater - intruded prevention | 249308 | 6.2 | 675768 | 16.8 | 688630 | 17.1 |
| | | Seasonally transitional zone | 485554 | 12.1 | 547290 | 13.6 | 591334 | 14.7 |
| | | EZ Affected by flood and saltwater intrusion | 589 | 0.01 | 7574 | 0.2 | 40914 | 1.0 |
| | | **Total areas** | **735450** | **18.31** | **1230632** | **30.65** | **1320878** | **32.89** |
| 3 | **Brackish water AEZ** | Brackish water AEZ | 700071 | | 700071 | | 700071 | |
| | | Brackish water AEZ with forest | 99440 | | 99440 | | 99440 | |
| | | **Total areas** | 799511 | 19.9 | 799511 | 19.9 | 799511 | 19.9 |
| Total areas of saltwater intrusion (2+3) | | | 1534961 | 38 | 2030143 | 51 | 2120388 | 53 |
| **Total study areas** | | | **4015632** | **100** | **4015632** | **100** | **4015632** | **100** |

- Flooded and semi-inundated area increased from 13.9% of total area (current) to 16.5% in 2030 and 19.2% in 2050.

The total area of saltwater intrusion (mainly salinity-prevented area) increased from 38% (present) to 51% in 2030 and 53% in 2050.

*c. Detailed aqua-zoning - detailed zoning (level 3)*

A summary of the potential of suitable land use types for aquaculture in certain periods in the 13 provinces of the Mekong Delta (excluding the area under current aquaculture) is presented in Tables 3.15, 3.16, 3.17

Table 3.15 Area (ha) of of landuse types suitable with mix/rotated aquaculture modelsat present

| No | Provinces | Types of landuse suitable with mix/rotated aquaculture models | | | | |
|---|---|---|---|---|---|---|
| | | Forest | Rice -1 season | Rice -1 season | Orchard | Total areas |
| 1 | Long An | 15247 | 23854 | 80704 | 16390 | 136194 |
| 2 | Tien Giang | 1306 | 40 | 7984 | 30643 | 39973 |
| 3 | Ben Tre | 134 | 18598 | | 46361 | 65093 |
| 4 | Tra Vinh | 5509 | 49025 | | 21734 | 76268 |
| 5 | Vinh Long | | 124 | | 5108 | 5232 |
| 6 | Dong Thap | 4683 | 1828 | 71117 | 1945 | 79574 |
| 7 | An Giang | 510 | 85751 | | 1669 | 87934 |
| 8 | Kien Giang | 6434 | 110506 | 31 | 24264O | 141234 |
| 9 | Can Tho | | | 7542 | | 7544 |
| 10 | Hau Giang | 363 | | 24144 | 15355 | 39867 |
| 11 | Soc Trang | 3631 | 5296 | 27705 | 21689 | 58322 |
| 12 | Bac Lieu | 1123 | 7646 | 5271 | 2253 | 16295 |
| 13 | Ca Mau | 16830 | 9890 | 1217 | 3774 | 31712 |
| **Total** | | 55772 | 312557 | 225716 | 191184 | 785242 |

Table 3.16: Area (ha) of of landuse typessuitable with mix/rotated aquaculture models2030

| No | Provinces | Types of landuse suitable with mix/rotated aquaculture models | | | | |
|---|---|---|---|---|---|---|
| | | Forest | Rice -1 season | Rice -1 season | Orchard | Total areas |
| 1 | Long An | 18438 | 29402 | 103901 | 19359 | 171100 |
| 2 | Tien Giang | 1821 | 41 | 12726 | 46987 | 61575 |
| 3 | Ben Tre | 199 | 31865 | | 80571 | 112635 |
| 4 | Tra Vinh | 5509 | 106163 | | 43122 | 154793 |
| 5 | Vinh Long | | 1153 | 8441 | 22539 | 32133 |
| 6 | Dong Thap | 5020 | 2172 | 75985 | 2399 | 85576 |
| 7 | An Giang | 569 | 93861 | | 1795 | 96236 |
| 8 | Kien Giang | 6762 | 128651 | 40 | 26665 | 162118 |
| 9 | Can Tho | 99 | | 22402 | | 22512 |
| 10 | Hau Giang | 812 | | 26084 | 20333 | 47231 |
| 11 | Soc Trang | 5664 | 5552 | 62141 | 25602 | 98959 |
| 12 | Bac Lieu | 1123 | 12283 | 6997 | 2529 | 22932 |
| 13 | Ca Mau | 18355 | 10509 | 1323 | 3771 | 33958 |
| **Total** | | 64371 | 421651 | 320039 | 295673 | 1101759 |

Table 3.17: Area (ha) of of landuse typessuitable with mix/rotated aquaculture models2050

| No | Provinces | Types of landuse suitable with mix/rotated aquaculture models | | | | |
|---|---|---|---|---|---|---|
| | | Forest | Rice -1 season | Rice -1 season | Orchard | Total areas |
| 1 | Long An | 20675 | 29402 | 114305 | 19604 | 183986 |
| 2 | Tien Giang | 2384 | 41 | 13052 | 50395 | 65872 |
| 3 | Ben Tre | 199 | 31924 | | 81167 | 113290 |
| 4 | Tra Vinh | 5509 | 106163 | | 43122 | 154794 |
| 5 | Vinh Long | | 1307 | 11130 | 25184 | 37620 |
| 6 | Dong Thap | 5511 | 2714 | 80092 | 3200 | 91517 |
| 7 | An Giang | 588 | 103580 | 42 | 2249 | 106460 |
| 8 | Kien Giang | 6801 | 143792 | 36 | 28191 | 178820 |
| 9 | Can Tho | 222 | | 32201 | 46 | 32486 |
| 10 | Hau Giang | 812 | | 26872 | 27307 | 54992 |
| 11 | Soc Trang | 5689 | 5610 | 76900 | 25998 | 114196 |
| 12 | Bac Lieu | 1123 | 22769 | 9722 | 2529 | 36144 |
| 13 | Ca Mau | 18397 | 11008 | 1323 | 3771 | 34499 |
| **Total** | | **67910** | **458310** | **365676** | **312762** | **1204676** |

- The model with one rice crop in rotation/combination with aquaculture has the highest potential with 312557ha (current), increasing to 421651 (2030), 458310ha (2050).

- The model with two rice crops in rotation/combination with aquaculture has the second largest potential with an area of 225716ha (current), up to 320039ha (2030), 365676ha (2050).

- The model of garden and pond in combination with aquaculture has the third largest potential with an area of 191184 hectares (current), increasing to 295,673 hectares in 2030, 312762 hectares in 2050.

- The model of forest in combination with aquaculture has the fourth largest potential with an area of 55,772 ha (current), increasing to 64,371 ha in 2030 and 67910 ha in 2050.

- In the 13 provinces in the Mekong Delta, Kien Giang and Long An are the two provinces with the greatest potential for promoting the development of aquaculture in rotation/combination with forest and agricultural production.

The spatial distribution of suitable areas for aquaculture regarding the types of land use is shown in Figure 3.8, Figure 3.9 (2030) and Figure 3.10 (2050).

### 3.2.2 AEZin extreme events and climate change conditions

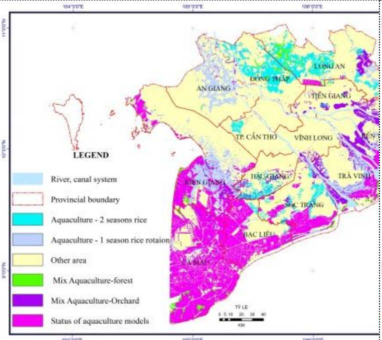



Figure 3.13: Suitable areas for aquaculture with current landuse

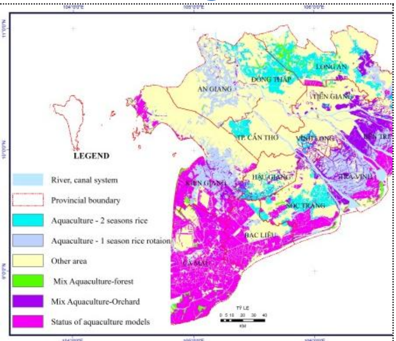



Figure3.14: Suitable areas for aquaculture with landuse in 2030

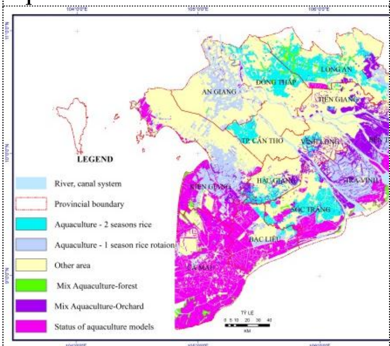



Figure 3.15: Suitable areasfor aquaculture with land use in 2050

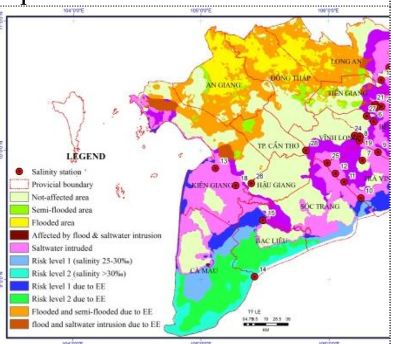



Figure 3.16: Dynamic AEZ due to current extreme events and CC

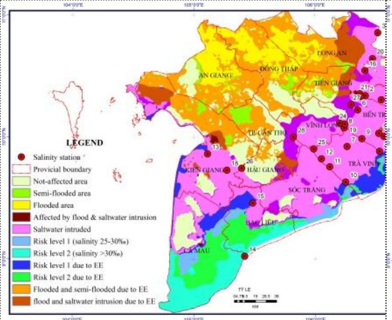



Figure 3.17: Dynamic AEZ due to extreme events and CC in 2030

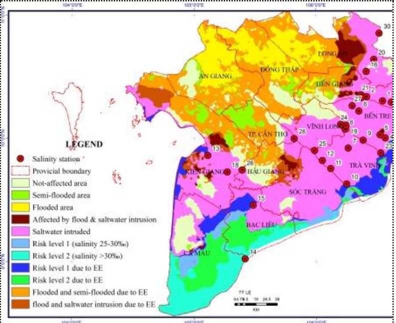



Figure 3.18: Dynamic AEZ due to extreme events and CC in 2050

The purpose of dividing these areas is to let managers see the excessive dynamics that can be made in years of extreme events. Based on ecological characteristics, managers can arrange and organize production to promote effectiveness and respond to extreme events' consequences and CC.

Table 3.16: Variation of AEZ caused by extreme events and CC

| No | Kinds | Scenario | | | | | |
|---|---|---|---|---|---|---|---|
| | | **current** | **%** | **2030** | **%** | **2050** | **%** |
| **I** | **Freshwater ecology** | | | | | | |
| | Not-affected area | 1153233 | 28.7 | 525841 | 13.1 | 403375 | 10.0 |
| | Semi-flooded area | 68758 | 1.7 | 94716 | 2.4 | 137004 | 3.4 |
| | Flooded area | 283958 | 7.1 | 318996 | 7.9 | 361578 | 9.0 |
| **II** | **Seasonal Ecotone** | | | | | | |
| | Saltwater intruded | 805533 | 20.1 | 1205994 | 30.0 | 1388867 | 34.6 |
| | Affected by flood and saltwater intrusion | 1230 | 0.03 | 7447 | 0.2 | 90912 | 2.3 |
| **III** | **Ecology of year-round brackish** | | | | | | |
| | Risk level 1 (salinity 25-30%) | 129865 | 3.2 | 94980 | 2.4 | 91183 | 2.3 |
| | Risk level 2 (salinity >30%) | 138810 | 3.5 | 238935 | 6.0 | 246796 | 6.1 |
| **IV** | **Dynamics in eco-region due to extreme events** | | | | | | |
| 1 | Salinity caused by extreme events | | 20.1 | | 15.8 | | 10.6 |
| | Saltwater intrusion caused by extreme events | 365992 | 9.1 | 209259 | 5.2 | | 0.0 |
| | Risk level 1 (salinity 25-30%) due to extreme events | 190732 | 4.7 | 215905 | 5.4 | 217706 | 5.4 |
| | Risk level 2 (salinity >30%) due to extreme events | 249342 | 6.2 | 209720 | 5.2 | 208464 | 5.2 |
| 2 | Flooded and semi-flooded due to extreme events | 578457 | 14.4 | 724050 | 18.0 | 722744 | 18.0 |
| 3 | Affected by flood and saltwater intrusion due to extreme events | 49551 | 1.2 | 169620 | 4.2 | 146832 | 3.7 |
| | **Total area** | **4015462** | **100** | **4015462** | **100** | **4015462** | **100** |

The results in Table 3.7 and Figures 3.16; 3.17 and 3.18 indicate that in 2050 there will be no saltwater intrusion caused by extreme events since this area will be converted to saltwater-intruded and flooded areas (3.7% of total area), on the other hand, the distribution of affected area depends on the terrain of the region. The total area of primary and secondary risk areas is always rising and there is a transition from primary level to secondary level in cases of extreme events: 708749 ha (present), 759540 ha (2030) and 764149 ha (2050).

## 3.3 Integrating AEZ in spatial planning

### 3.3.1 Functional zoning for ecological zones

Based on the characteristics of the models of aquaculture adapted to CC and the characteristics of the ecological sub-zones, the functions used in the aquaculture development of the sub-zones are described in Table 3.21

Table 3.21: Function assignment for AEZ

| TT | AEZ level 1 | AEZ level 2 | Functions |
|---|---|---|---|
| 1 | Brackish water AEZ | Brackish water AEZ | - To develop aquaculture in the form of specialized aquaculture throughout the year |
| 2 | | Brackish water AEZ and forest areas | - To develop mangrove aquaculture |
| 3 | Transitional AEZ | Seasonal brackish water AEZ | - To develop a model of rotating 1 brackish water aquaculture crop with 1 agricultural crop |
| 4 | | Preventing-salinity Brackish water AEZ | - To develop fresh water species for rotation/combination models or freshwater species which can grow in saltwater (tilapia, prawn, red snapper); Use measures to avoid saltwater intrusion caused by production activities |
| 5 | Freshwater AEZ | Freshwater AEZ moderatedly affected by floods | - To develop traditional farming creatures on lowland areas |
| 6 | | Freshwater AEZ with Semi-flooded | - To develop rotation and combination models in lowland and flooded areas under 3 months |
| 7 | | Flooded AEZ | - To develop rotation and combination models in agricultural areas for the target species in about 4 months |
| 8 | | AEZ of intruded by saltwater in dry seasons and affected by floods in rain seasons | - To develop freshwater species for rotation/combination models or freshwater species which can grow in saltwater (tilapia, crayfish, pinktail), taking measures to avoid saltwater intrusion caused by production activities |

### *3.3.2 Developing aquaculture models based on product chains in specific AEZ*

*(i) Expansion of aquacultural production*

Expand the production by raising shrimp in rotation and combination with agriculture in appropriate ecological zones

*(ii) Identification of appropriate target groups and seasons*

It is possible to raise white-leg shrimp in rainy seasons (due to low salinity); In dry seasons, giant tiger prawn should be raised at coastal estuaries while white-leg shrimp should be raised in areas with low salinity (deeper in inland area)

*(iii)Segmentation of production based on ecological characteristics*

Table 3.22: Salinity at different stages of shrimp development

| **Shrimp types** | **Suitable salinity for duration of shrimp aquaculture** | | | |
|---|---|---|---|---|
| | **Breeding production** | **Nursing for about 20 days** | **Reach the size of 5g/shrimp** | **Reach commercial size** |
| White-leg shrimp | 30% | 25-30% | 15-25% | 4-15% (size 20g/shrimp) |
| Giant tiger prawn | 30% | 25-30% | 10-25% | 10-25% (size 40-0g/shrimp) |

Innovation and reorganization of production can be arranged in a production chain based on the characteristics of shrimpdevelopment and the distribution of ecological regions. Arrangement according to the production chain in Table 3.12 to ensure matching with ecological characteristics of each region (risk minimization), as well as sharing risk and benefits in the chain of production. Meanwhile, it improves efficiency due to the specialization in production

## CONCLUSIONS AND RECOMMENDATIONS

### 1. Conclusion

(i) ***Scientific basis of aqua-ecological zoning in climate change condition***.

Aqua-ecological zoning in CC condition is based on a combination of four factors: (i) water ecology, (ii) natural features of the area; (ii) characteristics of aquaculture production in the area; (iv) the impact of CC.

- Ecological factors need to be considered in terms of hierarchical structure, spatial distribution and temporal variability of water ecology;

- Natural factors and CC that cause ecological changes affecting aquaculture production should be divided into external and internal factors as a basis for quantifying the spatial distribution of ecological zonesin future;

- Aquacultural production characteristics are the basis for selecting time frames for the zoning criteria and selecting the aquaculture adaptation models to be assessed.

***(ii) Aqua-ecological zoning in MeKong delta under climate change condition***

- *Coastal and tidal areas:* By 2050, there is no suitable aquaculture area in westernand the remain 104 ha in Easten side of the study area that caused bythe impact of sea level rise

- *Inland area*: CC causes shifts and fluctuations of transition and freshwater zone in the period to 2030.

The area of seasonally transitional aqua-ecological zone increased from 18.31% in the current scenario, 30.65% in the 2030 and 32.89% in 2050. Of which the salinity area(0-4‰)increase from 6.2% of current scenarios, 16.8% in 2030 and 17.1% in 2050 of scenarios.

The area of the freshwater ecological zone has decreased from 61.8% in the current scenario, from 49.4% in the scenario 2030 and 47.2% in the scenario 2050; in which semi-flooded areas and flooded areas increased from 13.9% of the total area (current) to 16.5% in 2030 and 19.2% in 2050.

***(iii) Impacts of climate change and extreme events***

The impact of CC and extreme events has increased the dynamics of water resources in drought years (compared with present time), increasing the current total area of saltwater intrusion up to 48.1%, to 58.6% in the 2030 scenario and 59.5% in the 2050 scenario; in which, risked area with aquaculture due to salinity> 25 % varies approximately at 18-20% of total area. Impacts of CC and extreme events have increased flooding (in comparison with the present) in extreme flood years (about 23.2% of total current area, 28.3% in 2030 and 30.4% in 2050).

***(iv) Aquaculture models for climate change adaptation***

Impacts of extreme events and CC create opportunities for expanding the area for the development of rotation and combination models between agriculture and aquaculture in the forms of land use: one rice crop, two rice crops, garden-pond and mangrove.

Integration of solutions to CC: (1) Adjust species by season for giant tiger prawn and white-leg shrimp to match the ecological characteristics of saltwater intrusion; (2) Restructure the production based on ecological characteristics of water resources; (3) Upgrade irrigation system and take measures to reduce salinity in coastal areas when the salinity is too high due to extreme events.

*The findings have contributed to scientific and practical foundation in working out the strategic orientations and general development planning on a regional and local scale. Promoting the adoption of abovementioned CC adaptation models will help achieve long-term goals in two ways: (1) Improving production efficiency, adapting to adverse impacts caused by CC; (2) Minimizing the impacts of CC and extreme events thanks to the creation of large reservoirs (water storage aquaculture models) to regulate the flow in the whole area during dry seasons*

## 2. Recommendations

1) When studying the impacts of CC on a detailed scale, the natural elements as inputs should be considered in detail: in space (increase in detail and resolution) and in chronological order (in months) so that the results get close to reality. Meanwhile, study on the assessment of environmental capacity should be added as a basis for identifying areas suitable for aquaculture.

2) Integration of aqua-ecological zoning scenarios into local socio-economic development strategies and in response planning development, enhancing the adaptation to CC and policies on livelihood.

3) Update the flow data of 2016 to make the results more sensible