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RESEARCH ON MANGROVE VEGETATION CHANGE IN THE COASTAL REGION OF NORTHERN VIET NAM IN THE CONTEXT OF CLIMATE CHANGE AND SEA LEVEL RISE

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SUMMARY OF DOCTORAL THESIS ON BIOLOGY

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INTRODUCTION

1. Necessity of the thesis research

Mangrove vegetation are of great importance to coastal protection against erosion, natural disaster prevention, reduction of tsunami-caused damage, alluvial trapping, nutrient accumulation, regulation and water cleaning ... Mangrove vegetation are also carbon sinks, which are able to accumulate carbon from CO2, contributing to reducing greenhouse gas (Phan Nguyen Hong, 1991; Phan Nguyen Hong *et al*, 1999, 2004; Kauffman and Donato, 2012; Nagelkerken *et al*., 2002).

Climate change becomes an urgent matter with a huge impact on the growth and survival of mangroves (Donald and Philippe, 2006). However, in the world as well as in Viet Nam, such impact has not yet been fully studied and evaluated and therefore, our understanding of growth, adaptation and change of mangroves in the context of climate change is still limited. Moreover, accurate prediction of the change of mangrove ecosystems under climate change scenarios can help propose solutions to proper management and plannning for each region to minimize risks and challenges for coastal areas (Ellison, 2004; Gilman, 2004; Hansen and Biringer, 2003).

Therefore, the implementation of the thesis research "*Research on mangrove vegetation change in the coastal region of Northern Viet Nam in the context of climate change and sea level rise*" is essential and of significantly scientific and practical importance.

2. Goal of the thesis research

The dissertation aims to predict mangrove vegetation changes in the coastal region of Northern Viet Nam (CRNVN) by 2050 under the impact of climate change and sea level rise. Since then, the thesis proposed technical solutions to contribute to the conservation and development of mangroves, preventing natural disasters and improving people's living conditions in the context of climate change and sea level rise.

3. Thesis contents

- Evaluate present status of mangroves in the coastal region of Northern

Viet Nam in terms of tree density, average tree size and mangrove species composition, diversity index, importance value, complex index, niches width, spatial distribution, which is concentrated in 3 locations representing 3 successive zones and sub-zones of coastal region of Northern Viet Nam;

- Develop relationships between tree density, average size, and mangrove species structure with temperature, precipitation and tidal inundation frequency;

- Predict the change of density, average size and structure of mangrove species in the study sites under climate change and sea level rise scenarios;

- Propose some solutions to contribute to the conservation and development of mangroves in the context of climate change and sea level rise.

4. The viewpoints

- Viewpoint 1: Mangrove forests are a dynamic system, usually changing under the impact of environmental change. When the climate changes, sea level rises, the mangroves will change in quantity (distribution area) and quality (tree density, tree size, biomass, species diversity and composition ...);

- Viewpoint 2: Mangrove species diversity and composition, tree density and size, and biomass of mangrove forests have relationships with temperature, precipitation and frequency of tidal inundation. These relationships can be quantified by the mathematical formula.

- Viewpoint 3: The analysis and evaluation of present status of mangrove forests, climate change and use of mathematical formula in terms of the relationships between diversity, species composition, density, size, and biomass of mangrove forests with temperature, precipitation and frequency of tidal inundation help predict the extent/level of mangrove change under climate change scenarios.

5. New findings of the thesis research

- This is the first time mangroves change till 2050 have been quantitatively assessed through quantitative parameters on diversity, mangrove species composition, tree density, size of mangrove forests and the relationship between such parameters and temperature, rainfall and tidal inundation frequency.

- Experimental basis with mathematical formula has been developed and

applied to predict the changes of mangrove forest and propose solutions contributing to the conservation and development of mangroves for the research sites in the coastal region of Northern Viet Nam in the context of climate change and sea level rise.

6. Significance of the thesis

- Scientific significance: The research findings of the thesis contribute to synthesizing and clarifying the scientific basis and methods of predicting the changes of mangrove forests in the context of climate change and sea level rise in the coastal region of Northern Viet Nam (CRNVN) by using formulas of the relationship between mangrove species diversity and composition, tree density and size, biomass with temperature, precipitation and tidal inundation frequency.

Preliminary contributions of the thesis can be used as a basis for further completing the prediction model of mangrove succession in the context of climate change and sea level rise not only for the CRNVN but also for other areas and the entire mangroves in Viet Nam.

- Practical significance: The research results of the thesis have shown the changes of mangrove forest in study sites in the CRNVN. That is an important basis to propose solutions contributing to the conservation and development of mangrove forests under climate change and sea level rise scenarios till 2050.

7. Timeline

- From December, 2012 to June, 2013: Literature review; Preparation of research plan, methodology and fieldwork plan.

- From July, 2013 to May, 2016: Data collection and analysis; scientific paper publishing.

- From June, 2016 to December, 2016: Writing thesis.

8. Thesis structure

Thesis consists of 112 pages, divided into sections: Introduction (05 pages); Chapter 1: Literature review (18 pages); Chapter 2: Study area, subject, scope and methodology (18 pages); Chapter 3: Results and Discussion (69 pages); Conclusions and recommendations (02 pages). The thesis has 15 tables; 30 figures of charts, diagrams and photos; 04 appendixes; 88 references, including 20 Vietnamese and 68 English documents.

CHAPTER I: LITERATURE REVIEW

The thesis analyzes and discusses the issues related to vegetation change, climate change and sea level rise, impact of climate change and sea level rise on vegetation, application of models to predict vegetation change in the context of climate change and sea level rise. In particular, the researches in the world and in Vietnam asserted that: mangrove vegetation is a changing system; temperature, precipitation and tidal frequency have a great influence on the growth and development of mangrove vegetation; climate change and sea level rise are of the important factors that make the change of mangrove vegetation.

However, studies on quantitative relationships between structural and growth mangrove vegetation with temperature, precipitation and tidal frequency are still insufficient. Therefore, predicting the trend of mangrove vegetation change in the context of climate change and sea level rise encountered many difficulties. Especially in Viet Nam, most of the predictions on the change of mangrove vegetation are of a qualitative nature, and there is no systematic study to quantify the change of mangrove vegetation in the context of climate change and sea level rise.

Therefore, this thesis proposes and quantifies mangrove vegetation change of CRNVN in the context of climate change and sea level rise to 2050 through study on structural, growth characteristics of mangroves, temperature change, precipitation, sea level, sedimentation, mathematical models of relationships of structural and growth characteristics of mangroves on temperature, precipitation and tidal inundation frequency. The research results contribute to the addition of scientific and experimental bases to apply mathematical models to predicting mangrove vegetation changes in the context of climate change and sea level rise.

CHAPTER II: STUDY AREA, SUBJECT, SCOPE AND METHODOLOGY

2.1. STUDY AREA

The coastline of Northern Viet Nam, including the coastal strip of the Quang Ninh, Hai Phong, Thai Binh, Nam Dinh, Ninh Binh and Thanh Hoa provinces was selected as the study area.

2.2. SUBJECT AND SCOPE

2.2.1. Research subject

Mangrove vegetation in the coastal region of Northern Viet Nam.

2.2.2. Research scope

The research has assessed changes in the density, tree size and structure of true mangrove species of mangrove forests till 2050 in the three study sites: Dong Rui (Tien Yen district, Quang Ninh province), Xuan Thuy National Park (Giao Thuy district, Nam Dinh province) and Da Loc commune (Hau Loc district, Thanh Hoa province) representing the CRNVN in the context of change in temperature, rainfall and sea level.

- Density, tree size and species structure were chosen for the study because they are the basic characteristics of mangroves, and can be changed when the environmental conditions (including climate) change. Density, tree size and species structure can be accurately quantified through field measurement.

- The thesis has focused on true mangrove group because these are species distributed in areas periodically flooded by tide (Phan Nguyen Hong et al, 1999) and therefore, it is possible to quantify the change in density, size and species structure when climate change causes changes in sea level and changes tidal inundation frequency. The remaining group- associate mangrove species grow on the grounds only flooded by high tide or freshwater land and has not been studied in this thesis. In addition, preliminary field survey also showed that the associate mangroves account for a very small percentage on pond embankments, high mound not or rarely flooded by tide.

- The study was done in Dong Rui (Tien Yen district, Quang Ninh province), Xuan Thuy National Park (Giao Thuy district, Nam Dinh province)

and Da Loc commune (Hau Loc district, Thanh Hoa province) because mangroves at each location are typical and representative of mangroves in the region with differences in geography, geology, hydrology ... according to the zoning of Phan Nguyen Hong (1991).

2.3. METHODOLOGY

2.3.1. Approach method

Systematic approach, comprehensive approach, space-for-time substitution approach… have been used in the thesis research with the hypothesis:

- The distribution, growth and development of mangrove species are influenced by the combined effects of environmental factors.

- Models of the relationship between mangrove vegetation characteristics and environmental factors are used uniformly before, during and after climate change and sea level rise.

- The distribution of mangrove species and the current status of mangrove vegetation is indicative of the ecological conditions at a given location, although previously there was a human impact.

2.3.2. Secondary data collection, inheritance method

Information, documents, data, maps related to research contents have been collected and used for inheritance, argumentation, and comparison… with findings of the thesis research.

2.3.3. Field survey method

- A total of 38 sample plots of 10 x 10 m in size on 13 research transects perpendicular to the coastline have been set up to collect data about the mangroves, sediment deposition and tidal inundation frequencies. Among them, 18 plots belong to Dong Rui, 12 plots in Xuan Thuy National Park and 8 plots in Da Loc. Sample plots and transects have been established by the method of Phan Nguyen Hong *et al*. (2004) and Nguyen Nghia Thin (2008).

- Mangrove data collection and calculation: species name, stem diameter and height, biomass, Shannon H’ diversity index, similarity index (Sorensen's Index), importance value (IV), complexity index (CI), niche width, spatial distribution according to Nguyen Nghia Thin (1997), FAO (2007), Sheue *et al.* (2003), Nguyen Hoang Tri (1996), Kauffman and Donato (2012), Nguyen Thi

Thu Hien and Tran Thi Thu Ha (2014), Misra (1968), Pool et al. (1977), Shannon and Wiener (1963), Upadhyay and Mishra (2014), Verma (2000).

- Collecting data on the deposition of sediments according to Nguyen Thi Hong Hanh and Mai Sy Tuan (2008), English *et al*. (1997).

- Collecting data and calculating tidal inundation frequency according to English *et al*. (1997) and Clough (2013).

2.3.4. Statistical, correlation and regression analysis

- One-way ANOVA was used to analyze the difference of mangrove vegetation and climate at different study sites.

- Pearson correlation analysis was used to evaluate the relationships between tree density, average tree size and species composition of mangrove vegetation with temperature, precipitation and tidal inundation frequency.

- Multivariate linear regression analysis was used to evaluate the relationship of tree density, average tree size and species composition of mangrove vegetation with temperature, precipitation and tidal inundation frequency. This regression relationship was then used to calculate mangrove vegetation change in the context of climate change and sea level rise.

2.3.5. Mapping method

The thesis inherited remote sensing images (including Landsat satellite imagery of the US, France 2010 SPOT image from the Center for Remote Sensing and GIS of the Forest Inventory and Planning Institute for digitization and maps of mangrove distribution. The mangrove distribution maps were created by using ArcGIS 9.3 and MapInfo 10.0.

CHAPTER III: RESULTS AND DISCUSSION

3.1. PRESENT STATUS OF MANGROVE FORESTS IN STUDY SITES

3.1.1. Present status of mangrove vegetation in Dong Rui

3.1.1.1. Mangrove extent and distribution

It is estimated based on the mangrove distribution map of Dong Rui commune that there are 2,900 ha of mangroves found on mud flats around the commune.

3.1.1.2. Mangrove species composition

The results of mangrove species composition along survey transects in Dong Rui showed 15 true mangrove species belonging to 13 genera, and 12 families. This result is perfectly consistent with the results of Do Dinh Sam et al. (2005) on the number of mangroves species in Tien Yen area.

3.1.1.3. Mangrove species structure and diversity

The results on the mangrove species diversity and composition in Dong Rui showed that *A. corniculatum* is the most important species with the highest importance value (IV = 34.18%), followed by *B. gymnorrhiza* (IV = 24.7%), *K. obovata* (IV = 21.97%), *R. stylosa* (IV = 10.18%), *A. marina* (IV = 6.05%), and *S. caseolaris* (IV = 2.92%). The mangrove species structure in Dong Rui has not been so well separated that one or two species dominate and overwhelm the remaining species.

3.1.1.4. Tree density and size, and biomass

Research results show that mangroves in Dong Rui has a density of about 7,900 trees/ha, the average stem diameter of about 5.1 cm, the average height of about 2.1 m, and biomass of approximately 112.7 tons/ha. The study results also reveal that these figures fluctuate markedly between standard plots in different locations.

3.1.2. Present status of mangrove vegetation in Xuan Thuy National Park

3.1.2.1. Mangrove extent and distribution

It can be found from the study that Xuan Thuy National Park covers 1,518 ha of mangroves. Mangrove vegetation is distributed mainly in Con Ngan and Con Lu. However, the northern part of Con Ngan, mangrove vegetation has been reduced due to the large part of being converted to aquaculture such as fish, shrimp and clam. In the south of Con Ngan, Con Lu (in Giao An, Giao Lac and Giao Xuan communes) mangrove vegetation tends to increase, as hundreds of hectares of mangrove trees have been planted with support from institutional, domestic and foreign organizations together with local efforts to preserve and develop mangrove vegetation.

3.1.2.2. Mangrove species composition

The results of mangrove composition along the survey transects in Xuan Thuy National Park show 12 true mangrove species of 11 genera and 9 families. However, as compared to Phan Nguyen Hong et al. (2004), two species of *Lumnizera littorea* and *Nypa fruiticans* are no longer found in this study. That can be explained by the *Nypa fruiticans*, which was imported from the South and no longer survived; *Lumnizera littorea* was extinct in the wild and is only grown at the research station of the Mangrove Ecosystem Research Center in Giao Lac commune.

3.1.2.3. Mangrove species structure and diversity

The results showed that *K. obovata* is the most important and the most dominant species (IV = 48.94%), followed by *A. corniculatum* (IV = 39, 76%), *S. caseolaris* (IV = 8.24%) and *R. stylosa* (IV = 3.06%). As such the importance of both species *K. obovata* and *A. corniculatum* accounted for almost 90%, overwhelmingly dominate the remaining species.

3.1.2.4. Tree density and size, and biomass

Research results show that mangroves in Xuan Thuy National Park has a density of about 6,900 trees/ha, average diameter of approximately 6.3 cm, average height of 1.7 m and biomass of about 230.6 tons/ha.

3.1.3. Present status of mangrove vegetation in Da Loc commune

3.1.3.1. Mangrove extent and distribution

The survey result shows that mangrove vegetation in Da Loc commune has been formed for a long time but not much researched. From 1952-1953, the total mangrove area of the commune was about 20 hectares. After that, the area of mangroves decreased seriously. However, by the end of the 1980s, with the attention of local authorities and later with support from national and international organizations such as the Japanese Red Cross, the British Children's Foundation, the CARE Foundation ... hundreds of hectares of mangroves has been restored and protected. Computed results show that the mangrove vegetation in Da Loc commune is about 415 ha.

3.1.3.2. Mangrove species composition

The survey on mangrove species composition along the transects in Da Loc commune displays that the commune has 9 true mangrove species,

belonging to 9 genera and 8 families. In particular, *K. obovata* is also a major participant in tree floor, other species such as *A. corniculatum*, *R. stylosa*, *S. caseolaris* alternate with *K. obovata*, but in small quantity. The remaining species are recorded only in small numbers, grass plants, shrubs on pond banks or in areas that are less affected by tides such as *A. aureum*, *A. ilicifolius* or *S. portulacastrum*. Some species, such as *L. racemosa*, *B. gymnorrhiza*, have been recorded in the CRNVN but not in Da Loc.

3.1.3.3. Mangrove species structure and diversity

The results show that in Da Loc commune, *K. obovata* has absolute dominance of importance value up to 72.88%, strongly overwhelm the remaining species such as *A. corniculatum*. IV = 1.99), *R. stylosa* (IV = 12.83%) and *S. caseolaris* (IV = 12.40%).

3.1.3.4. Density, tree size and biomass of mangroves vegetation

Research results show that mangroves in Da Loc commune has an average density of 10,188 trees/ha, the average diameter of approximately 8.66 cm trunk, the average height of approximately 3.0 m and biomass of about 441.93 tons/ha.

3.1.4. Comparison of present status of mangrove forests in research sites

3.1.4.1. Mangrove extent and distribution

The comparison shows that the mangrove area in Dong Rui and Xuan Thuy National Park is much larger than the area of mangrove forest in Da Loc. Dong Rui and Xuan Thuy has favorable topographical conditions, location and fertile soil; as a result, mangroves grow well with a large distribution area. Meanwhile, the coastal mudflats in Da Loc commune short and more deeply inundated compared to Xuan Thuy National Park; moreover, Da Loc is not surrounded by the islands like Dong Rui; consequently, the protection and restoration of mangroves is very difficult as they are frequently prone to tropical storms from the sea, strong waves and tides.

3.1.4.2. Mangrove species composition

Study sites have fairly considerable similarity in true species composition. Specifically, the similarity index between Dong Rui and Xuan Thuy National Park is 0.89; Dong Rui and Da Loc is 0.75 and Xuan Thuy National Park and Da Loc is 0.86. Comparative results show that sites closer together such as Dong Rui- Xuan Thuy National Park or Xuan Thuy National Park-Da Loc have

a larger similarity index than in distant study sites such as Dong Rui- Da Loc.

3.1.4.3. Mangrove species structure and diversity

Diversity of true mangrove species is the highest in Dong Rui (H = 1.1), followed by Xuan Thuy (H = 0.7) and the lowest in Da Loc (H = 0.4). In contrast, the most complex mangroves are observed in Da Loc (CI = 23.0), followed by Dong Rui (CI = 14.6) and Xuan Thuy (CI = 8.0).

Though study sites are fairly similar in species composition (SI > 75%), only *K. obovata* and *R. stylosa* are the two species that are fairly evenly distributed in standard plots in the three study sites. As a result, the thesis research covers the calculation and comparison of the importance of the three species, and species group including *K. obovata*, *R. stylosa* and other species in different research locations (Figure 3.9).

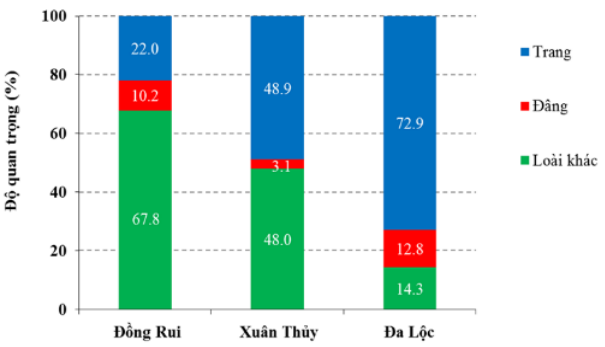

Figure 3.9. Mangrove species structure in research sites

3.1.4.4. Tree density and size, and biomass

The results show that tree density in Dong Rui (7,900 trees/ha) and Xuan Thuy (6,925 trees/ha) is significantly lower than in Da Loc (10,188 trees/ ha). The tree size also gradually increases from Dong Rui (stem diameter of 5 cm, height of 2.1 m) to Xuan Thuy (6.3 cm in stem diameter, 3.6 m in height) and Da Loc (8.7 cm in stem diameter, 3.0 m in height). The difference may be due to Dong Rui, although less affected by the winds because of the outside shielding islands, but in winter when the northeast monsoon come to our country, Dong Rui has air, soil and water temperature drop, even a sudden drop, has stifled the growth and development of mangroves. The impact of the northeast monsoon decrease at Xuan Thuy and Da Loc areas.

3.2. IMPACTS OF CLIMATIC CONDITIONS AND SEA LEVEL ON MANGROVE VEGETATION

3.2.1. Climatic conditions and sea level in study sites

Annual mean temperature gradually increased from 23°C in Dong Rui to 23.7^{o}C in Xuan Thuy and 24.3^{o}C in Da Loc; the rainfall has changed more

complicatedly; the highest was found in Dong Rui (2324.9 mm/year), and the lowest in Xuan Thuy (1582.8 mm/year) and the average sea level in research sites for the period of 2001-2014 was 193.0 cm.

3.2.2. Impacts of temperature, precipitation, and tidal inundation frequency on mangrove forests

3.2.2.1. Impacts of temperature, precipitation, and tidal inundation frequency on tree density and size

It can be confirmed from research results that tree density and size has a close correlation with temperature, precipitation and frequency of tidal inundation ($R \geq 0,5$; $p < 0,05$). Detailed evaluation showed that tree density, stem diameter and tree height have a positive linear relationship with the temperature (that is when the temperature increases, these figures also go up), but stem diameter and tree height do not fully follow this rule (i.e. when rainfall increases, these figures are not on a rise); and tree density tends to be stable when rainfall increases. The study results also showed that when tidal inundation frequency rises (i.e. in places more frequently flooded by tide), the tree density and height seem not to increase.

3.2.2.2. Impacts of temperature, precipitation, and tidal inundation frequency on species diversity and mangrove species structure

The study results showed diversity index (Shannon index) is closely correlated with the temperature, rainfall and tidal inundation frequency ($R \geq 0,6$; $p < 0,05$). Mangrove species diversity is inversely proportional to temperature and tidal inundation frequency, but proportional to rainfall (which means species diversity decreases as temperature and tidal inundation frequency rises, but increases as the rainfall increases).

Concerning the relationship between the importance value (IV) of study species and temperature, precipitation, and tidal inundation frequency, it has been found that IV of *K. obovata* and *R. stylosa* is closely correlated with temperature, precipitation, and tidal inundation frequency. IV of *R. stylosa* reduces but IV of *K. obovata* goes up when temperature and tidal inundation

frequency is on a rise. By contrast, IV of *R. stylosa* rises and IV of *K. obovata* goes down when precipitation increases.

3.2.2.3. Overall impacts of temperature, precipitation and tidal inundation frequency on mangrove forests

The results of regression analysis (Table 3.12) show that the R coefficients of the models ranged from 0.61 to 0.93 ($p < 0.05$). In which, models of density, tree height, trunk diameter, diversity index (Shannon index) and importance value of *R. stylosa* and *K. obovata* with temperature , precipitation and tidal inundation frequency have a high R-coefficient, respectively 0.69; 0.75; 0.61; 0.81; 0.73 and 0.93, ie, temperature, precipitation and tidal inundation frequency, can account for about 69% of changes in density, 75% of changes in tree height, 61% Trunk diameter, 81% of variation index variations (Shannon index), 73% changes in importance value of *R. stylo*sa and 93% changes in importance value of *K. obovata*. F test also shows that the above models are statistically significant ($p < 0.05$). This result is also consistant with the correlation analysis above.

Theoretically, the higher the regression coefficient R the higher the reliability of models in explaining the variation of the dependent variable (ie, higher R value is a sign that the relationship between the independent variable and the dependent variable is more stringent). However, the minimum value for the regression coefficient is only relative. Therefore, we apply these regression models to the calculation and compare the results with the actual measurements in the plots to test the accuracy and evaluate the practical applicability of the regression models. In comparison with real values, the results calculated from the regression models showed a relatively low error (<10%) and in the present research conditions, the results of predicting the changes of mangroves will be used to find out orientations for the future in the context of climate change and sea level rise, the error below 10% of all the prediction model above is acceptable.

Table 3.12. Regression models of density, tree size, diversity index and species important values on temperature, precipitation and tidal inundation frequency

No.	Model				R	F	p
	Dependent variable	**Independent variable**	**Parameter**	**Standard parameter**			
1	Density (tree/ha)	Constant	-138669.407		0.69	3.347	0.03
		Temperature	5909.169	1.120			
		Precipitation	7.042	0.890			
		Tidal inundation frequency	-71.569	-0.287			
2	Tree height (m)	Constant	24.218		0.75	5.094	0.005
		Temperature	-0.731	-0.306			
		Precipitation	-0.003	-0.775			
		Tidal inundation frequency	0.014	0.126			
3	Stem diameter (cm)	Constant	-62.728		0.61	2.756	0.047
		Temperature	2.749	0.369			
		Precipitation	0.001	0.078			
		Tidal inundation frequency	0.032	0.089			
4	Shannon index *H'*	Constant	2.988		0.81	8.639	<0.001
		Temperature	-0.075	-0.080			
		Precipitation	0.001	0.374			
		Tidal inundation frequency	-0.017	-0.390			
5	Important value of *R. stylosa* (%)	Constant	107.376		0.73	2.815	0.044
		Temperature	-5.441	-0.201			
		Precipitation	0.018	0.343			
		Tidal inundation frequency	-0.031	-0.023			
6	Important value of *K. obovata* (%)	Constant	-436.635		0.93	31.238	<0.001
		Temperature	19.753	0.298			
		Precipitation	-0.040	-0.392			
		Tidal inundation frequency	1.197	0.390			

3.3. CHANGES OF MANGROVES IN THE CONTEXT OF CLIMATE CHANGE AND SEA LEVEL RISE

3.3.1. Temperature, rainfall, and sea level under climate change scenarios

Climate change scenarios for Viet Nam were reported by Ministry of

Natural Resources and Environment (MONRE, 2012) according to different greenhouse emission scenarios: at low, medium and high levels. This thesis research used the medium emission scenario as well in the analysis related to climate change in the coastal region of Northern Viet Nam. (Table 3.14).

Table 3.14. Temperature, rainfall, and sea level under climate change scenarios

Criteia	Year	Dong Rui	Xuan Thuy	Da Loc
Average annual temperature (^oC)	2020	23.8	24.2	24.8
	2030	24.0	24.5	25.0
	2040	24.3	24.8	25.3
	2050	24.5	25.1	25.5
Average annual precipitation (mm/year)	2020	2224.5	1646.2	1759.3
	2030	2239.9	1655.9	1769.8
	2040	2255.3	1668.9	1780.2
	2050	2272.9	1681.9	1792.4
Average annual sea level (cm)	2020	198.2	193.3	196.4
	2030	200.1	186.9	195.2
	2040	202.5	181.0	194.5
	2050	206.4	176.6	195.3

3.3.2. Sediment deposition-a factor changing tidal inundation frequency

The sediment accretion measured in Dong Rui, Xuan Thuy National Park and Da Loc are 3.2, 10.4 and 5.2 mm/year respectively, much higher than the sea level rise rate at only 1.9 mm/year, as mentioned in part 3.2.1.2. So, in these areas, the ground has continued to rise, meaning that the mudflat area is likely to continue expanding.

3.3.3. Vulnerability to climate change of mangrove vegetation

According to field surveys and analysis of data on climate, tide, forest area changes, biological characteristics and probable expansion of mangrove forest area at the study sites based on the criteria of assessing mangrove vulnerability to climate change, it could be found that the mangroves in Xuan Thuy National Park are less vulnerable than in Dong Rui and Da Loc. However, with the average vulnerability rating of about 1.86-2.29 and in comparison with the results from Ellison (2012), the vulnerability of mangrove forests at study

sites to climate change is still low, which means that mangrove forests in this area are fairly well resistant to climate change.

3.3.4. Changes of mangrove vegetation in study sites

3.3.4.1. Changes of mangroves in Dong Rui

The study results indicated that by 2050, in the context of climate change and sea level rise, mangrove tree density and size will increase while these figures will not change significantly in non-climate change condition. Tree height and stem diameter will change the most; in the phase of 2030-2050, tree height will possibly double and stem diameter may be on a 1.5 fold increase compared to the present height and diameter. This result can be explained by climate change (increases the temperature and precipitation) that have boosted the growth and development of mangroves.

It can also be seen from the study results that from now till 2050, in the context of climate change and sea level rise, IV of *K. obovata* and *R. stylosa* will be likely to nearly double from 22% in 2015 to 38.7% in 2050 for *K. obovata* and from 10.2% in 2015 to 22.3% in 2050 for *R. stylosa*; IV of the remaining species will reduce considerably from 67.8% in 2015 to 39% in 2050. If climate change does not occur, IV of *R. stylosa* will rise markedly from about 10.2% to 26.7%; IV of *K. obovata* will also go up but insignificantly in this stage, from 22% in 2015 to 24.3% in 2050; IV of the remaining species may reduce from 67.8% in 2015 to 49.1% in 2050. Thus, looks at the whole process of change, *A. corniculatum*, *B. gymnorrhiza*, *K. obovata* and *R. stylosa* are now dominant in Dong Rui mangrove vegetation, but up to 2050, *R. stylosa* and *K. obovata* will gradually dominate and overwhelm the remaining species.

3.3.4.2. Changes of mangroves in Xuan Thuy National Park

The research findings indicated that in the context of climate change and sea level rise from now (2015) to 2050, the mangrove ecosystem is predicted to develop fairly stably at the tree density of about 8,000-9,000 trees/ha, and with an increase of 20-30% in height and diameter compared to the year 2015. Meanwhile, in non-climate change condition, mangroves will gradually degrade

with reduced tree density and markedly reduced diameter and height, being 1,400 trees/ha, 5.3 cm and 0.9 m respectively. This result indicated that in non-climate change condition, many mangrove trees could not survive or die; some trees could survive and regenerate with much smaller average diameter and height.

It can be found from the research that in the context of climate change and sea level rise, IV of species will still be fairly stable till 2050. This finding is totally contrary to the estimations in case of climate change absence; in such conditions, mangrove species structure undergoes remarkable changes. Especially from 2030 to 2050, IV of *K. obovata* is predicted to reduce from about 46.2% to only 22.2% while IV of *R. stylosa* will rise from 7.2% to 21.3% and IV of the remaining species may change insignificantly

The above results can be explained by the sedimentation rate in Xuan Thuy National Park is very high (10.9 mm/year) and if the sea level does not change or change little, the ground will be raised to make the tidal inundation frequency in Xuan Thuy National Park decrease rapidly, followed by many changes in salinity, pH, nutrition ... in the soil. All of these changes will no longer be suitable for mangrove species, and mangrove vegetation will be degraded and after 2050 mangroves may be replaced by a more suitable ecosystem.

3.3.4.3. Changes of mangroves in Da Loc

From now to 2050, mangroves in Da Loc will develop fairly stable in both conditions with and without climate change. In both cases, the density and size of trees will increase. The structure of mangrove species will also be greatly variable; IV of *K. obovata* may increase from 72.9% in 2015 to 86.3% in 2050 in a stable climatic condition and rise to 89.6% in climate change condition. The importance value of the remaining species is predicted to decrease from 27.1% in 2015 to 13.7% in stable climatic conditions and to 10.4% in climate change conditions. Therefore, by 2050, *K. obovata* will continue to be dominant and overwhelm the remaining mangroves in the mangrove forest in Da Loc. This result may be due to the fact that the history of mangrove vegetation development in this area is mainly

due to *K. obovata* reforestation from 10-20 years ago. Other species such as *S. caseolaris* or *R. stylosa* are also planted but with low density and low survival rates as compared to *K. obovata*.

3.3.4.4. General evaluation of changes of mangrove vegetation in the context of climate change and sea level rise

The thesis was focused on three sites representing three consecutive zones, subzones in CRNVN, but the results of the thesis, field observations and synthesis of Phan Nguyen Hong *et al*. (1999, 2010) [9], [10] in provinces of CRNVN (Quang Ninh, Hai Phong, Thai Binh, Nam Dinh, Ninh Binh and Thanh Hoa) mangroves have the same characteristics with one of the representative study sites. Therefore, the research results of the thesis may represent the CRNVN.

All above study results indicated that in the coastal region of Northern Viet Nam, ecological succession of mangrove forests by 2050 will have not witnessed the complete replacement of the current mangrove ecosystem with a new ecosystem completely different in terms of species composition, structure, dynamics and relations. However, mangrove ecosystems in the coastal region of Northern Viet Nam will change in two distinct trends:

- The first trend (for the mangroves in Dong Rui and Xuan Thuy National Park): the mangrove forests will degrade naturally with declined density, tree size and change in species composition. In the context of climate change and sea level rise, the rate of degradation will be slower than in non-climate change condition. In particular, in Xuan Thuy National Park, by 2050 mangroves will have been degraded with a significant decline in tree density and size.

- The second trend (for the mangroves in Da Loc): mangroves will develop steadily under both climate change and non-climate change conditions with stable tree density and size, and insignificant change in species structure.

The calculations in the context of climate change and sea level rise also show that the mangroves at research sites still develops steadily until 2050. The density and size of trees are stable but the structure of the species changes. This result is also consistent with the results of Gilman (2004) that mangroves still

develop and keep pace with sea level rise. That means that when sea level rise occurs but the sediment is still accreted and sediment accretion rate is higher or equal to the sea level rise, the mangrove vegetation is less affected.

a) *b)*

c) *d)*

Figure 3.30. Mangrove development to the sea (a) and some human activies affecting mangrove development: clam culture (b), clam digging (c) and land use change for shrimp culture (d)

Thus, mangroves in general and mangroves in the coastal region of Northern Viet Nam in particular play a role in responding to and mitigating the impacts of climate change; however, mangrove forests are directly affected by climate change. In addition to the temporary negative effects of extreme weather events such as strong winds, storms, cyclones or tornadoes, changes in temperature, precipitation and sea level rise may help to maintain the development of mangroves, slowing or preventing the mangrove degradation process.

All these calculations and analysis are based primarily on the natural development and change of mangrove forests due to climate change. In reality, human beings have always had direct or indirect impacts on mangrove forests through activities such as dyke making, mangrove felling and conversion of mangrove forest land to agricultural production, aquaculture, shipping, building of seaports and industrial parks near mangroves or marine harvesting in mangroves, mangrove planting, etc. Human activities can inhibit the natural development of mangroves and directly affect the results of the above prediction calculations (Figure 3.30b,c,d). Therefore, the results of this thesis research will be the basis for further evaluation of possible changes of mangrove forests under human influence so as to accurately predict the ecological succession of mangrove forests. This can serve as a basis for the conservation and development of coastal mangrove ecosystems.

3.4. SOME PROPOSED SOLUTIONS TO MANAGEMENT AND DEVELOPMENT OF MANGROVES IN THE CONTEXT OF CLIMATE CHANGE AND SEA LEVEL RISE

3.4.1. Grounds for proposing solutions

Study results showed that from now (2015) to 2050, in the non-climate change case, mangroves will be prone to degradation and likely to encroach seaward; In conditions of climate change, mangroves also tend to be degraded but at a slower rate and less degraded. The most deterioration will take place in Xuan Thuy National Park followed by Dong Rui and Da Loc. Therefore, in order to preserve and develop mangroves, men should take intervention actions (through solutions of policy, scientific research, technology, socio-economic and education-training) in order to create conditions for smoothy and quick regeneration of forests towards the newly formed and stable mudflats.

3.4.2. Solutions to management and development of mangroves in the context of climate change and sea level rise

These guiding bases are the basic foundation for proposing concrete solutions that positively impact on the change of mangrove vegetation in the

context of climate change and sea level rise. Solutions of policy management, scientific research, socio-economy or education-training ... are identified as fundamental solutions and always needed. However, with the scope and research contents on ecology, the thesis focuses on technical solutions to ensure the sustainable development of mangrove vegetation. Details are as follows:

** Facilitate to maintain the development, slow down the current recession of the current mangrove vegetation:*

The results of analyzing the change of mangrove vegetation in the study sites (section 3.3.4), especially in Xuan Thuy and Dong Rui National Park show that mangrove vegetation tends to be degraded. Therefore, it is necessary to have specific technical solutions in order to maintain the development or slow down the recession of mangrove vegetation.

- For sites with fast recession of mangrove vegetation due to sedimentation accretes the elevation, especially in places where sediment accretion rate is much faster than sea level rise e.g. Xuan Thuy Natinal Park (study results in 3.3.2), dominant mangrove species such as *K. obovata*, may die, their regenerated seedlings are underdeveloped or their viability is poor (results of study in 3.3.4.2). Therefore, in order to prolong the development of the *K. obovata*, it is possible to dig water channels into low tidal areas, keep the ground moist and provide drainage channels, spread the seedlings to the surrounding area. However, it is less costly and more appropriate to adopt alternative planting methods that are less tolerant to flooded land. Mangrove species can be planted on high land such as *Lumnitzera racemosa*, *Acrostichum aureum* or *Hibiscus tiliaceus*, etc. This is human positive effect on the process of mangrove vegetation change to ensure a stable and timely adaptation to climate change and sea level rise.

- For sites where mangrove vegetation is degraded by aquaculture ponds preventing the water flowing to mangroves (the survey results in Dong Rui (see 3.30d) clearly show this), it is needed to reak down the banks of the ponds and try to ditch the drainage channels to limit the area of land fragmented and some

part of the land without periodic flooding, leading to rapid mangrove recession. At the same time it is necessary to study on planting mangrove species different from the current species of *R. stylosa* or *B. gymnorrhiza* ... in order to increase diversity and ensure the stable development of mangrove vegetation.

** Create space and favorable conditions to promote the development of mangrove to the sea:*

- The research results show that mangrove vegetation is changing in trend of degradation in current position and if there is enough space mangroves could develop naturally to the sea. Development of aquaculture such as clams and shrimps on the outside and encapsulation of the current mangrove vegetation in the provinces of study area makes no space for natural development of mangroves, stopping the process of mangrove succession. The results of analysis in Section 3.3.4.4 in this thesis have shown this. Thus, if there is not any plan on planning and creating space for development of mangroves, mangroves will be degraded and disappeared, protection capacity of mangroves will be cancelled. Planning and creating space for development of mangroves is considered as an important and essential technical solution in the coastal provinces of North Vietnam.

- Analyzes of the composition of mangrove species in the newly formed mudflats are mainly pioneer species such as *A. marina* in Dong Rui, *S. caseolaris*, *K. obovata* in Xuan Thuy National Park, Da Loc. Therefore, in these areas, it is necessary to study and apply techniques to reduce the waves (such as bamboo fences, netting ...) to create favorable conditions for development of the trees and mangrove seedlings of *K. obovata*, *S. caseolaris* and *A. marina* regenerate on newly formed and stable mudflats. At the same time, to accelerate the development of pioneer trees on the new stable mudflats, make additional mangrove planting. For example, for estuarine areas such as Ba Lat, Tra Ly or Len, boats operate continuously, besides frequent winds, *S. caseolaris* are grown in nursery 1-3 years, then plant them on the newly formed and stable mudflats will have higher survival than natural regenerated trees on the mudflats.

The simultaneous application of the above solutions slows down mangrove degradation and accelerates the regeneration of mangroves to the sea. This can help maintain the sustainable development of the mangrove vegetation, to maintain the important protective functions of mangrove vegetation.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Mangrove vegetation in coastal region of Northern Viet Nam is developed, but the composition of mangrove species is limited with 15 species belonging to 13 genera, 12 families, in which *R. stylosa* and *K. obovata* are distributed and involved in the dominant species group at all study sites. Tree density is about 7,900-10,188 trees/ha; Average height is relatively low, about 2.1-3.6 m and average diameter of stem is quite small, about 5.0-8.7 cm.

2. Density, tree size (height, stem diameter), diversity index (Shannon index) and importance value of the two dominant species (*K. obovata* and *R. stylosa*) of mangrove vegetation in the CRNVN are strongly influenced by climatic and hydrological factors such as temperature, rainfall and tidal inundation frequency ($R = 0.61$ to 0.93, $p < 0.05$).

3. Calculation with mathematical model shows that by 2050, mangrove vegetation at CRNVN has not been altered by a vegetation or other ecosystems with different composition, structure, dynamics and relationships, but they could change in 2 trends:

- Mangrove vegetation naturally declines with reduced plant density, tree size and species composition change. The changes of mangrove vegetation in Dong Rui and Xuan Thuy National Park are typical examples. However, in the context of climate change and sea level rise, the mangroves is more stable and less degraded than in non-climate change condition.

- Mangrove vegetation developes stably in both assumptions of climate change and non-climate change conditions with stable tree density and tree size,

species composition change but not much. A typical example is the change of mangrove vegetation in Da Loc.

4. By 2050, mangrove vegetation in some locations will change in the decline trend. Therefore, it is necessary to have a comprehensive solutions on management policies, scientific research, technology, socio – economic, and education and training ... to protect and develop mangrove vegetation. In particular, it should focus on two impotant technical solutions to create favorable conditions to maintain the development and slow down the current recession of the current mangroves: 1) is the technical solutions to slow down the vegetation degradation process in the area which is gradually accreted; the solutions could be digging water channels, breaking the banks of the water flow, planting trees tolerant to the low tidal land; 2) is the solutions to create space and favorable conditions to promote the development of mangroves to the sea; the solutions could be planning land for mangroves to develop to the sea to; applying wave-reduction technology against erosion, combining with mangrove planting, protecting the seedlings...

RECOMMENDATIONS

1. One of the important contents of the thesis research is the prediction of mangrove succession in the context of climate change and sea level rise which has been done for the first time in the coastal region of Northern Viet Nam; the data have been collected only in the three study sites, so it is necessary to continue collecting data to improve the effectiveness of the predicting models.

2. Regression models in general and mangroves' ecological succession predicting models in this thesis research in particular are "local" in nature; this means that they can be applied only in areas where the data for building these models are collected. Therefore, when these models are applied to other sites, they need to be adjusted by adding the data collected at those sites.

LIST OF SCIENTIFIC PAPERS RELATED TO THE THESIS RESEARCH

1. Pham Hong Tinh, Nguyen Thi Hong Hanh and Mai Sy Tuan, 2016. Relationship between climatic condition and mangrove forest structure on northern coast of Vietnam. *Journal of Science and Technology* 54(4): 443-451. (Journal of Viet Nam Academy of Science and Technology)

2. Pham Hong Tinh and Mai Sy Tuan, 2015. Vulnerability to climate change of mangroves in Xuan Thuy National Park, Vietnam. *ARPN Journal of Agricultural and Biological Science* 10(2) (ISSN: 1990-6145): 55-60. (Journal of Asian Research Publishing Network)

3. Pham Hong Tinh and Mai Sy Tuan, 2015. Quantifying the indices of biodiversity and distribution of woody true mangroves in the northern coast of Viet Nam. *Journal of Biology* 38 (1): 53-60. (Journal of the Viet Nam Academy of Science and Technology).

4. Pham Hong Tinh, Nguyen Thi Thu Hang, Lai Thi Thao and Mai Sy Tuan, 2015. Vulnerability of mangroves to climate change in the northern coast of Viet Nam. *Proceedings of the 6th national scientific conference on ecology and biological resources*. Publisher of Natural Science and Technology, Viet Nam Academy of Science and Technology: 1723-1728.

5. Pham Hong Tinh, Pham Duc Cuong and Mai Sy Tuan, 2014. Assessment of vulnerability to climate change for mangrove ecosystem: methodology selection and preliminary application results. *Proceedings of the 2nd national scientific conference on marine biology and sustainable de*velopment, Publisher of Natural Science and Technology, Viet Nam Academy of Science and Technology: 305-313.

6. Pham Hong Tinh, Nguyen Thi Hong Hanh and Mai Sy Tuan, 2016. Multivariate linear regressions of biodiversity and species composition of woody true mangroves to temperature, precipitation and tidal flooding frequency on northern coast of Viet Nam. *Proceeding of the 2nd national scientific conference on biological research and teaching in Viet Nam*, Vietnam National University Publishing House, Ha Noi, 810-817.