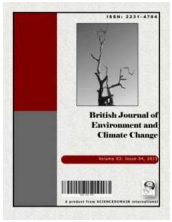

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Climate Change Challenges for Sustainable Coastal Wetland Management in Xuan Thuy Ramsar Site, Vietnam

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors initiated and conducted the research. Author HTT wrote the first draft of the manuscript while author HY revised the manuscript drafts. Both authors read and approved the final manuscript.

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ABSTRACT

Climate change has been recognized as a global threat and is already affecting ecosystems such as coastal wetlands. With more than 3,200 km of coastline, wetlands are the dominant ecosystem in Vietnam. This country is considered to be one of the most seriously affected by climate change in the world. Hence, coastal wetlands are vulnerable. This study applied the Drivers - Pressures - State - Impacts - Responses approach to discuss and analyze the main challenges induced by climate change and its potential consequences for Xuan Thuy Ramsar site in the Red River delta, Vietnam. In this research we used both observed and predicted data on the impacts of climate change issued by the Ministry of Natural Resources and Environment, Vietnam, including changes in temperature and rainfall, and sea level rise. The results illustrated numerous potential impacts and pressures associated with climate change on the study site. Understanding the effect of these potential impacts on wetland ecosystems is very important for managers and policy-makers because current conservation programs in Xuan Thuy Ramsar site have not included climate change issues. In addition, the complexity of synthesis impacts associated with global climate change is also a big challenge for local stakeholders. Our review suggests that a long-term conservation planning to response to climate change is crucial rule towards sustainable management of Xuan Thuy Ramsar site.

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Keywords: Climate change; coastal wetlands; ecosystems; impacts; Ramsar site.

1. INTRODUCTION

The Ramsar sites are wetland areas of international importance for ecosystem conservation. Ramsar sites, protected areas, are created to conserve global biodiversity and ecosystem for our society. The importance of wetlands in general, including Ramsar sites presents through very diverse services they provide and biological diversity they conserve [1]. Wetlands covers 6% of the global land surface and contain about 12% of global carbon pool, playing an important role in carbon cycle and ecosystem services [2]. In recent decades, traditional wetland management has succeeded in ecosystem conservation and restoration, however future climate change will likely present greater challenges for long-term wetland conservation [3].

Climate change has been recognized as a major threat to the survival of species and the resilience of ecosystems throughout the world [4]. Wetlands, as dynamic systems, are changing naturally over time as a consequence of processes such as hydrology, erosion, sedimentation and coastal flooding [1]. However, wetlands are likely to be vulnerable in the face of climate change [5,6] because the current management approach may not be adequate as changes in global climate [7]. The Scientific and Technical Review Panel of the Ramsar Convention on Wetlands (2002) highlighted that coastal wetlands will be significantly reduced due to sea level rise by 2025, and more seriously by 2100 [8]. Furthermore, Nicholls, Hoozemans and Marchard (1999) estimated that 22% of global coastal wetlands could be lost by 2080 due to rainfall change and sea level rise [9].

In Vietnam, wetlands cover more than 10 million hectares [10], of which 104,973 hectares were officially designated as six Ramsar sites by 2014 [11]. Therefore, wetlands can be found easily in most ecological regions of the country. Over the last 25 years, after joining Ramsar convention in 1989, Vietnam has initiated dozens of efforts to manage and conserve wetlands, particularly in coastal areas. However, the efforts have not fully satisfied the requirements of the three main pillars of the Ramsar convention: wise use, sustainable conservation, and wetland development [10]. The existing pressures induced by human activities combined with the challenges caused by climate change pose serious threats to wetland systems in Vietnam. Current climate change scenarios for Vietnam have predicted significant changes in rainfall, temperature, sea level rise, and extreme weather events in the future [12]. While these changes have interdisciplinary impacts on wetlands, traditional measures for wetland protection mainly focus on individual aspects and/or sector dimensions such as biodiversity conservation, water resources management, agriculture and aquaculture planning, or livelihood development. Importantly, climate change has not been integrated into wetland management yet. This situation can seriously affect wetland sustainability. This paper discusses and analyzes the main challenges caused by climate change for a typical coastal wetland, Xuan Thuy Ramsar site by using the drivers - pressures - state - impacts - responses (DPSIR) approach. This study aims to illustrate each of elements of DPSIR framework with particular reference to climate change implications for study area.

2. MATERIALS AND METHODS

This study was based on data available in the literature. We reviewed numerous reports from domestic and international institutions, and published papers related to wetlands and Xuan Thuy Ramsar site. In addition, the study also referred to documents related to climate change and sea level rise in Vietnam to analyze drivers, pressures, state, impacts and responses in study site.

2.1 Description of Study Site

2.1.1 Physical features

Xuan Thuy Ramsar site is located in the Red River estuary in northern part of Vietnam at latitude 20°10' - 20°17'N and longitude 106°21' - 106°33'E [10]. In 1989, Xuan Thuy was designated as the first Ramsar site in Southeast Asia, and the 50th site in the world. It became a national park in 2003. This Ramsar site is a vast area of coastal wetlands, covering a total of 15,100 hectares with a core zone (fully protected area) of 7,100 hectares and a buffer zone of 8,000 hectares [13]. The whole area is very low and lies on the coastal plain, with an altitude ranging between 0.5 and 0.9 m [14].

The Ramsar site is surrounded and protected by more than 3,200 hectares of mangrove forest [15] and belongs to the tropical monsoon region.

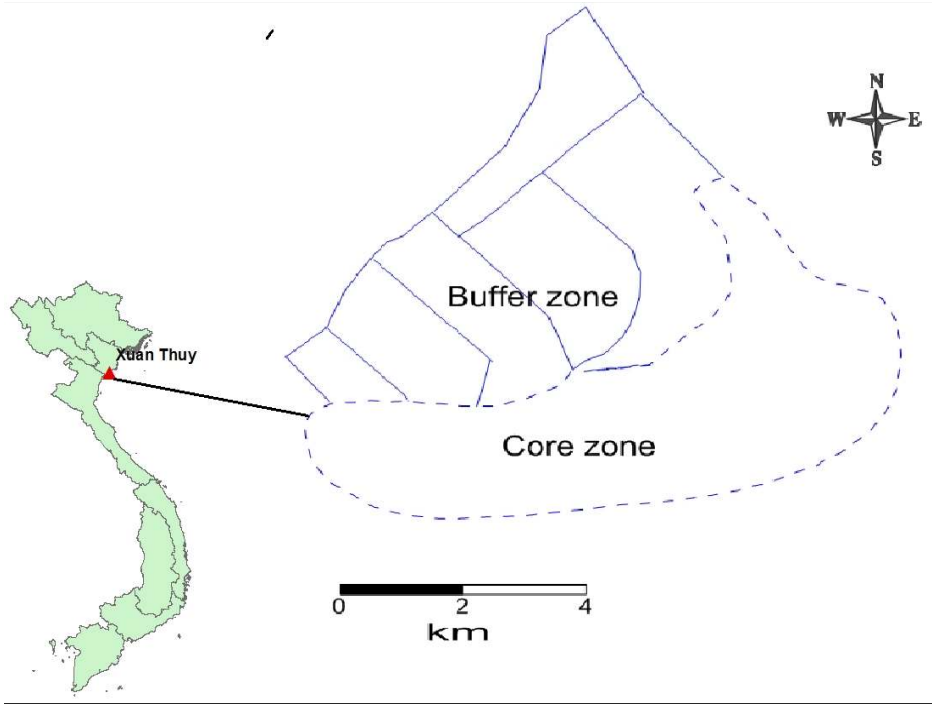

Fig. 1. Xuan Thuy Ramsar site

This region is characterized by two different seasons: hot and rainy from April to October; and cold and dry from November to March. The area has high rainfall (1,700 to 1,800 mm per year) and rich biodiversity that provides a favorable habitat for migratory water-bird species, especially some globally threatened species [15].

2.1.2 Socio-economic features

Since the Ramsar site belongs to a highly productive land of the Red River delta, socio-economic activities are very dynamic, especially in the four communities located in the buffer zone. There are about 48,000 people living in the buffer zone with a high density of 1,246 persons per km^2 [15]. The local people primarily depend on the exploitation of natural resources in the buffer zone through agriculture, aquaculture and fishing activities. The distribution of land use and labor are presented in Figs. 2a and 2b.

Land is used for different purposes between the core zone and buffer area. The core zone is strictly protected, covered by mangrove forest, mudflats and surface water, whereas the buffer zone is used for agriculture, intensive aquaculture, and villages for the local people.

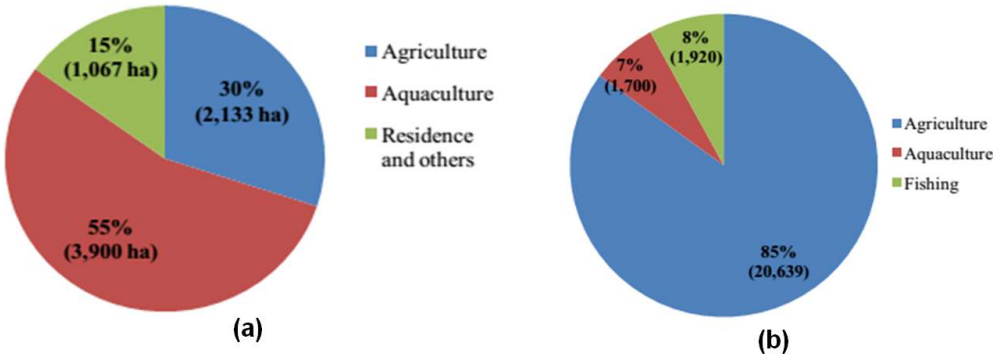

Fig. 2. Distribution of land use (a) and labor (number of people) (b) in the buffer zone of Xuan Thuy Ramsar site [15]

In recent years, biodiversity conservation and natural resource management in Xuan Thuy Ramsar site have faced with several pressures, including (1) over-exploitation of natural resources in the buffer zone; (2) biodiversity degradation; (3) wastewater discharge; and (4) low awareness of the local people about the environmental implications of their activities [14,15].

2.2 Drivers - Pressures - State - Impacts - Responses (DPSIR) Approach

The DPSIR approach has been applied worldwide in environmental research. It was developed originally by the Organization for Economic Cooperation and Development [16], and later by the European Environment Agency [17]. The DPSIR is an important tool for analyzing and proposing plans and programs in environmental and integrated water resources management [18], and integrated coastal zone management [19]. It can be used to investigate the changes of ecological structures, landscapes and functions of wetlands under the impacts of nature and human activity [20].

In general, the DPSIR framework starts by describing the driving forces (drivers) caused by human activity and natural processes which exert pressures and change the state of the environment and ecosystems. Then, it analyses the impacts of those pressures on the ecosystem functions, which finally require a response from society (Fig. 3). The description of the five general categories of DPSIR and their application to the topic of climate change as used in this paper are summarized below:

-*Driving forces* are the social, economic and demographic aspects of our society that change lifestyle, consumption and nature. All of these factors aggravate the impacts of climate change.

-*Pressures* are the consequences of driving forces that can induce environmental change. Basically, they are unexpected changes with the potential to cause the environmental degradation [21]. Pressures vary across geographic regions and spatial scales, for instance, pressures caused by climate change and sea level rise.

-*State* refers to the status of a natural system and socio-economic background in a certain area. In this study, the state of the wetland area refers to its physical, chemical, biological and social features.

-*Impacts* are the negative effects, or potential effects, caused by pressures on the state of the ecosystems. They eventually slow down ecosystem functions and services resulting in undesirable changes to the environment and human wellbeing.

-*Responses* show the actions taken by society to respond to the impacts on the ecosystem and human beings. They aim to prevent, compensate and/or adapt to changes by developing policies and management actions.

Overall, DPSIR is a useful and efficient tool for estuarine and coastal ecosystem assessment whether applied individually or combined with other tools [22]. Recently, several studies have applied this approach in different coastal ecosystems [20,23,24,25,26].

3. RESULTS AND DISCUSSION

In this section we describe what we found in the literature for each of the components of the DPSIR framework. For each component we will first describe the typical factors for wetlands, and then the specific ones for Xuan Thuy Ramsar site. It will be finished with a discussion of the most relevant ones for the study site.

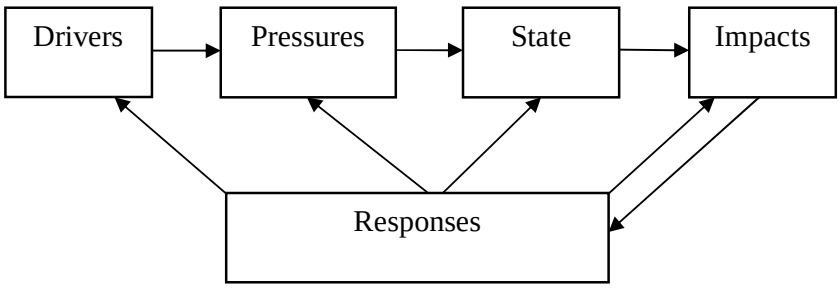

Fig. 3. DPSIR framework [27]

3.1 Driving Forces of Climate Change

The driving forces of climate change are divided into two sub-categories: "natural" which can be evaluated but not controlled; and "anthropogenic" which originate from human activity and can be assessed and controlled [20]. Global environmental and climate change is already causing negative impacts at a local and regional scale, thus increasing the pressure on ecosystems.

In terms of the “natural” drivers, wetlands themselves are important carbon sources and sinks. They emit a large amount of greenhouse gases (GHGs) into the atmosphere and directly contribute to climate change [28a]. IPCC (2007) reported that wetlands, along with rice agriculture, livestock, landfills, forests and termites, contribute to more than 70% of the methane emission from biogenic sources [28b]. In addition, land use change and loss of mangrove forest caused by human activity also contribute significantly to the emission of GHGs.

Obviously, anthropogenic drivers, namely, local and regional development has contributed to GHGs emissions and climate change. The amount of GHGs emissions have increased considerably in Vietnam during the last two decades because of population growth, industrialization, urbanization, land use change, and forest degradation. The three main GHGs sources are energy, agriculture, and land use/land use change and forest (LULUCF) which account for more than 90% of the current emissions [29,30]. Overall, emissions increased from 103.84 million tons of carbon dioxide equivalent (CO_2 eq) in 1994 to 150.9 million tons CO_2 eq in 2000. Emissions are predicted to increase significantly in the future as shown in Fig. 4.

The mangrove forest constitutes the most important carbon sink in the tropical region and it presents high capacity for carbon storage, which can range from 719.2±38.0 to 802.1±12.3 MgC per hectare in the coastal area of Vietnam [31]. However, the area of mangrove forest decreased dramatically from 1943 to 2000 (Fig. 5). This decreased carbon storage capacity has increased release of GHGs into the atmosphere.

According to our literature search, the driving forces of change in the Xuan Thuy Ramsar site can be divided into population growth, agriculture and aquaculture development, and tourism. Firstly, as mentioned previously, the buffer zone of the Ramsar site has a high population density that is still growing [15], which can lead to resource overexploitation. Secondly, 75% of the buffer zone is used for agriculture and aquaculture. Traditional farming uses a large amount of chemical fertilizers and feed which are released into the water environment, easily reaching and polluting the core zone of the Ramsar site [14]. Thirdly, on-site tourism development may affect the stability of wetland ecosystem even though the impacts have not been well documented.

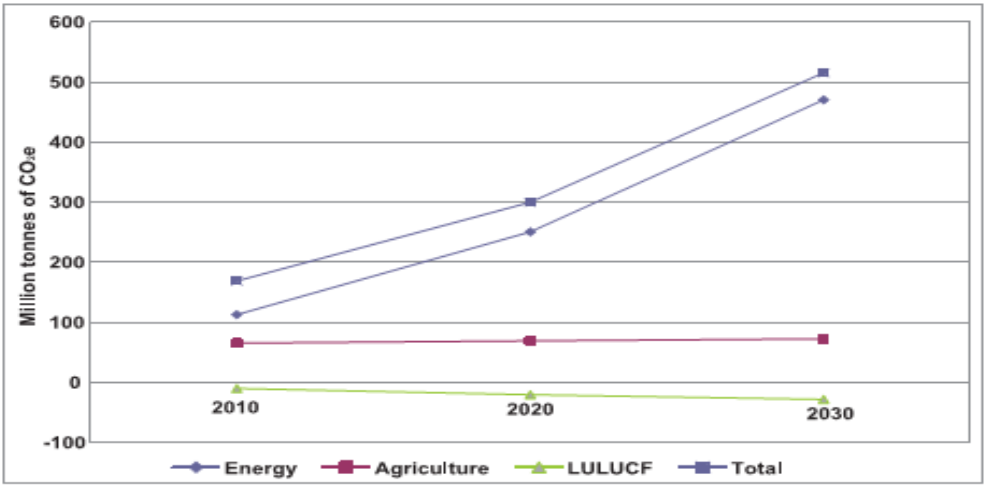

Fig. 4. GHGs emission projection in Vietnam for 2010-2030 [30]

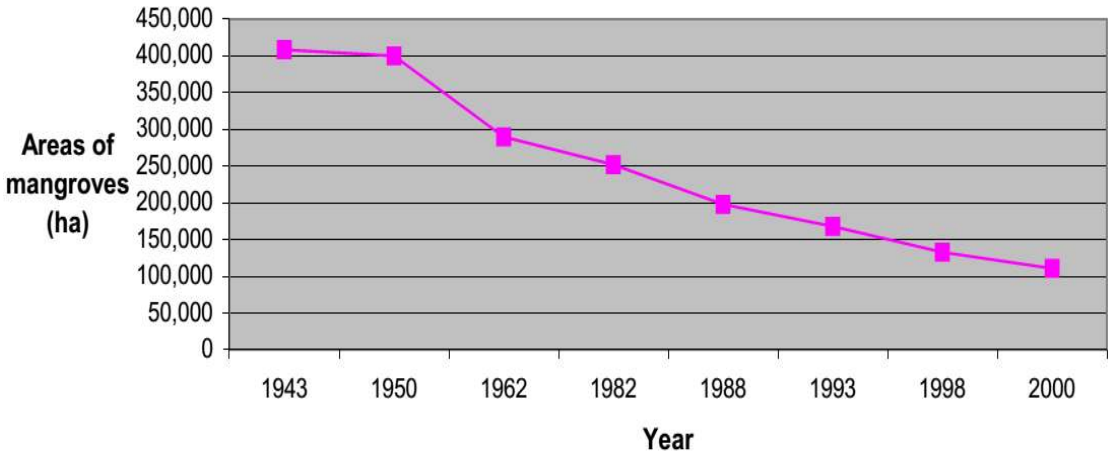

Fig. 5. Decrease in mangrove forest areas in Vietnam 1943-2000 [32]

3.2 Pressures Induced by Climate Change

The pressures related to climate change affect coastal wetland ecosystems mainly include temperature and rainfall changes, sea level rise, and extreme weather events. These changes have high potential impacts on ecosystems, coastal wetlands in particular [33]. The impacts are different among wetlands. Shallow areas seem to be the most vulnerable to drying, warming and change in water quality [34], whereas coastal areas, like the Xuan Thuy Ramsar site, are likely to be affected particularly by projected changes in temperature, precipitation and sea level rise [35], as described below.

In Vietnam, climate change has been observed and predicted for regions in accordance with global GHGs emission scenarios. Over the past 50 years (1958-2007), the annual mean temperature increased approximately 0.5 - 0.7℃ [36]. In particular, temperature increased more during winter and in inland areas than in summer and in coastal areas [12]. It is predicted that temperature change will be faster in the future along with increase of GHGs emissions. The current climate change scenarios predicts that annual temperature might increase by 1.2 -1.6℃, and 2 - 3℃ by 2050 and 2100 respectively, compared to 1980 - 1999 period [12]. The increase in temperature varies from region to region within Vietnam as presented in Figs. 6a and 6b.

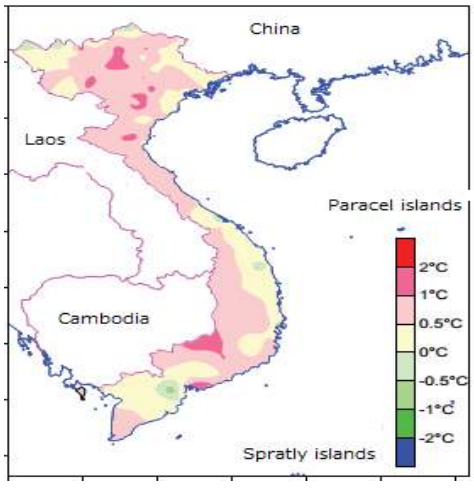

Fig. 6a. Observed increase in annual temperature over the last 50 years [12]

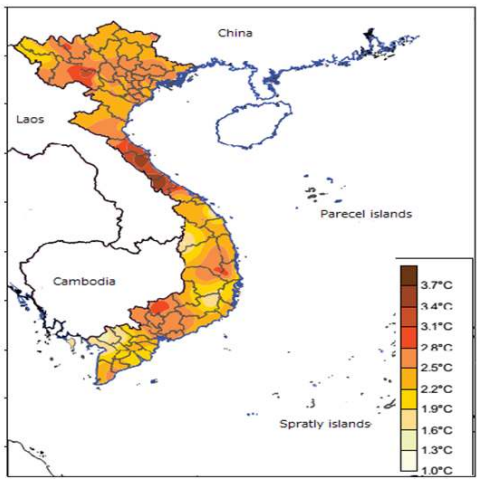

Fig. 6b. Predicted increase in annual temperature in Vietnam by 2100 [12]

Annual rainfall increased about 2% over the past 50-year period reaching 1,500 to 2,400 mm per year in Vietnamese regions [36]. However, rainfall increased in southern areas but decreased in northern areas (Fig. 7a). Based on climate change projections, rainfall will increase faster in the future in Vietnam; it will likely increase by 6 - 7% by 2100 [12]. Furthermore, rainfall tends to increase in the rainy season and to decrease in the dry season. As a consequence, change and uneven distribution of rainfall could affect regions through pressure and risk related to water availability and access. These trends will be expanded across the country as shown in Fig. 7b.

Sea level rise is likely a major threat to coastal ecosystems in Vietnam. Over the past 50 years, the observed data shows that sea level rose by 20cm along coastline of the country [36], with the Red River and Mekong River delta being the most affected areas [12]. Sea level is expected to continue rising in the future to up to 57-75cm by 2100 (Table 1).

Finally, extreme weather events have seriously affected coastal areas in recent decades. Oanh, Thuy, Wilderspin, and Coulier, (2011) summarized the impacts of floods and storms in Vietnam from 1989 - 2010 and found that there was an increase in the number of these disasters in coastal areas [37]. Even though the correlation between climate change and extreme weather events is controversial, it is clear that these extreme events have caused significant damage on coastal wetland ecosystems. Fig. 8 shows the distribution of major climate events in Vietnam. It indicates that the Red River delta (including Xuan Thuy Ramsar site) is already facing most disasters, for instance storm surges, typhoons, floods.

3.3 The State of Ecosystems in Xuan Thuy Ramsar Site

The state of the wetland ecosystem in Xuan Thuy Ramsar site was outlined by following main indicators: ecological structure (landscape), biodiversity, water resources.

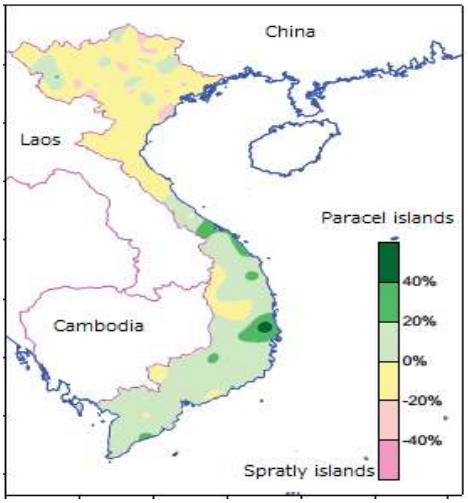

Fig. 7a. Observed increase in annual rainfall over the last 50 years [12]

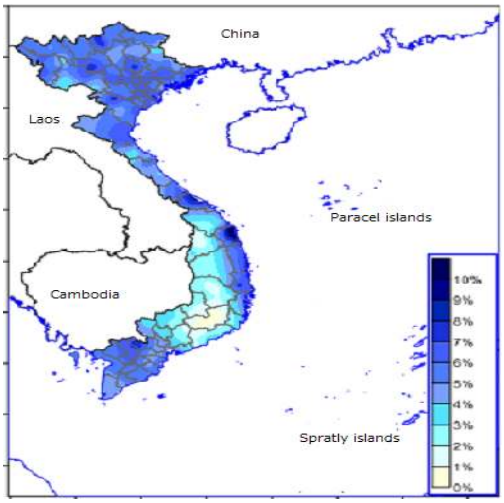

Fig. 7b. Predicted increase in annual rainfall in Vietnam by 2100 [12]

Table 1. Projected sea level rise (cm) relatively compare to 1980-1999 in Vietnam [36]

Scenario	Decades in the 21st century								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low emission scenario (B1)	11	17	23	28	35	42	50	57	65
Medium emission scenario (B2)	12	17	23	30	37	46	54	64	75
High emission scenario (A1FI)	12	17	24	33	44	57	71	86	100

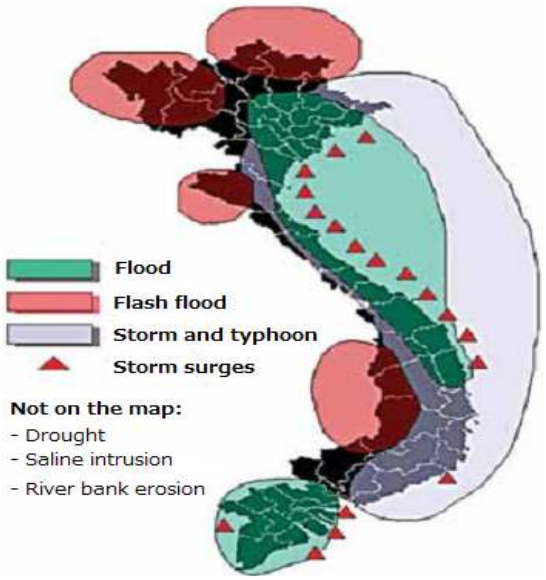

Fig. 8. Current geographic distribution of the main areas exposed to climate hazards in Vietnam [38].

The Ramsar site is characterized by a diverse estuarine ecosystem structure (Fig. 9) [39]. Mangrove forest is the dominant ecosystem surrounding the Ramsar site with 3,486ha, covering 25% of the core zone area and 22% of the buffer zone area [13]. It forms a narrow barrier from 0.5 to 3.5 km wide to protect the Ramsar site while the alluvial areas are situated between the estuary flows [40]. This structure supports the habitat of both natives and migratory species. In addition, the mangrove forest in Xuan Thuy Ramsar site plays an important role in protecting the wetland ecosystem, as well as providing a natural dyke system that prevents the damage caused by floods, waves and storms. In the buffer zone, there is a combination of agricultural ecosystem, aquatic ponds, and mangrove forest. These components help local people maintain their livelihoods and cultural services, as well as reducing the impacts of human activity to the core zone of the Ramsar site.

Xuan Thuy Ramsar site has been recognized for its rich biodiversity, which includes over 1,514 classified fauna species, and hundreds of flora and fauna species under classification [39]. Many species of migratory water-birds have been monitored in Xuan Thuy Ramsar site and some are considered under threat of extinction, for instance, *Tringa guttifer* (Spotted Greenshank); *Eurynorlrychus pygmeus* (Spoon-billed Sandpiper) and *Platalea minor* (Black-faced Spoonbill) [41]. Mangrove forest comprises both natural and planted areas, in which natural mangrove mainly includes *Bruguiera gymnorrhiza* and *Kandelia candel*, with a wide scattering of *Sonneratia caseola*, *S. caseolaris*, *B. gymnorrhiza, Aegiceras corniculatum*, *K. candel* and *Acanthus iliciflius*.

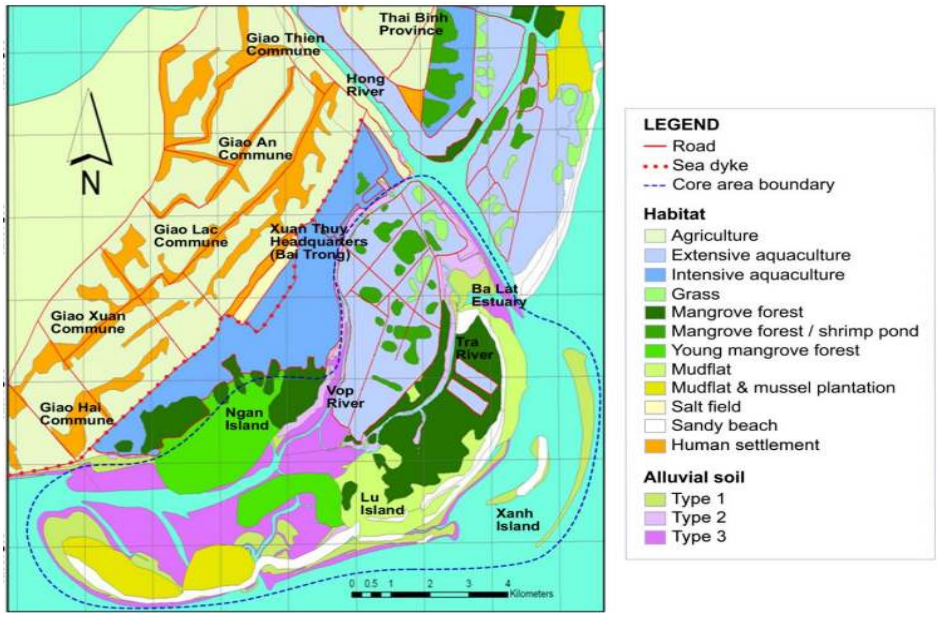

Fig. 9. Land use and ecological structure in Xuan Thuy Ramsar site [43]

While, *Phragmites vallatonia* is planted in large clumps in aquaculture ponds, together with *B. gymnorrhiza* and *A. corniculatum* [42].

Water resources are likely the core component of wetland ecosystems. Tinh, Hai, Loi, and Hung (2013) conducted a research on water quality in Xuan Thuy Ramsar site [44]. They took 46 samples of water from the whole wetland area and analyzed pH, BOD, COD, total nitrate, total phosphorus, total *E*. *Coli* and heavy metals (Pb, Hg, Mn, Fe). The research found that concentration of almost parameters are within Vietnam national technical standards on surface water quality, except BOD and COD in some positions near domestic wastewater discharging points. However, there are many economic activities implemented in the buffer zone such as fishing, shrimp, clam and crab ponds, rice and vegetable cultivation. These all can discharge unpredicted amounts of pollutants into the water environment at the Ramsar site and exert pressures on wetland ecosystem [15].

3.4 Potential Impacts of Climate Change on Wetland Ecosystems in Xuan Thuy Ramsar Site

Coastal areas are transitional zones where processes are controlled by complex interactions and flows of material between land, ocean and atmospheric systems. These processes make coastal zones one of the most changeable environments on Earth. The natural factors related to climate change expected to have the largest impacts on coastal ecosystems are temperature change, sea level rise, water availability from rainfall and river runoff, wind patterns and storminess. All these factors are not acting individually on a specific part of coastal system, but are connected in many ways and associated with human activity [45,46].

3.4.1 Impacts of climate change on water resources

Future projected climate change is expected to further complicate water resources management issues because of the increasing uncertainty regarding future rainfall [47]. The water availability of the Xuan Thuy Ramsar site depends heavily on the Red River water variation. The Red River basin originates in China and shares 16.4% of flow volume with the country's river system [48]. Under the impacts of climate change, annual river flow is predicted to increase by 2% to 5% by 2050 and 2100 compared to the period 1980-1999, respectively [48]. However, it is noted that river flow changes seasonally and regionally in accordance with the changes in rainfall and temperature. River flow will increase in the rainy season, but likely decrease in the dry season by 4% to 12% by 2100 [48]. As a result, wetland ecology will be affected by flooding during rainy periods, and by heat in the dry period. This will damage species survival and wetland resilience in the future.

In Vietnam, the Red River basin is likely to be the most vulnerable to climate change [48]. Air temperature increase due to climate change can lead to significant increase in evapotranspiration in the river basin. Therefore, this trend will affect hydrological cycles, water balance and river flow directly. Moreover, the increase in evapotranspiration will result in an increase in moisture loss in the basin when rainfall decreases in the dry season and will eventually reduce river flow. Also, this will boost water demand for irrigation in the wetland areas. All these factors will increase the pressure on water resources in wetland areas. On the other hand, the Red River flow depends significantly on water exploitation in upstream parts before reaching the Xuan Thuy Ramsar site. Therefore, water availability in the Ramsar site will be affected by upstream activity. Moreover, it is difficult to evaluate potential impacts of construction of dams and hydropower plants in the upper parts of the river. This situation, together with climate change, could accumulate impacts on water resources in Xuan Thuy Ramsar site.

Climate change also has a long-term impact on water quality. Recent studies have found significant linkages between climate change and surface water quality. Lunchakorn, Suthipong, and Kyoung (2008) applied Pearson's correlation to determine the relationship between climatic, hydrological and water quality parameters in downstream Mekong River flows through four countries (Lao, Thailand, Cambodia and Vietnam) [49]. The research found significant correlations between the studied parameters, in which rainfall, mean water level, discharge flow and mean air temperature have relative positive correlations with total suspended solid (TSS), NO_3^-, PO_4^{3-}, total phosphorus, and COD of water. Meanwhile, hydrological parameters presentes negative correlations with DO, pH, conductivity, Ca, Mg, Na, K, alkalinity, SO_4^{2-} and Si. The research concludes that TSS, alkalinity and conductivity would be considered as sensitive water quality parameters for monitoring impacts

of climate change. Similarly, Drewry, Newham, and Croke, (2009) also found positive correlations between total phosphorus, total nitrate, suspended solids and river flow [50].

Van Vliet and Zwolsman (2008) measured a total of 24 water quality parameters to assess the effects of changes in discharge and water temperature on concentration of chemical substances in the Meuse River during droughts [51]. The research found a general deterioration of water quality with respect to water temperature, eutrophication, major elements and some heavy metals. Among water quality parameters, concentration of dissolved organic matter, micro-pollutants and pathogens are likely to rise as a result of temperature increase and heavy rainfall in temperate countries [52].

Peter, Jill, and Timothy [53] reviewed numerous scientific evidences and noted several broad conclusions regarding the potential impacts of climate change on water quality. As concluded, direct short-term change in climate has led to significant change in water quality, especially in ecological transitional zones, and areas of natural climate extremes are vulnerable to changes of temperature and/or precipitation variability. In addition, changes in water quality caused by storms, droughts, and high air temperature can result such conditions that exceed the resilience capacity of an ecosystem, and thus lead to water quality degradation.

Due to its location in a river mouth, water resources in Xuan Thuy Ramsar site are susceptible to sediment accumulation. Duc, Nhuan and Ngoi [54] found that sediment deposits at Xuan Thuy wetland has increased up to 100 meters in length per year; and the rapid accretion and severe erosion by tides and waves have affected Xuan Thuy Ramsar site. Therefore, water resource in the Ramsar site will deteriorate.

3.4.2 Impacts of climate change on biodiversity

Biodiversity is the basis of agriculture, aquaculture, and forest ecosystems, as well as soil conservation and water quality. However, climate change combined with human activity, has affected biological diversity over the levels imposed by nature in recent decades [55].

Climate change impacts on biodiversity have been documented according to main indicators, including changes in phenology, species distribution and physical changes [35]. Phenological changes have been recorded in several species [56]. For instance, birds are laying eggs earlier [57,58], plants are flowering and fruiting earlier [59], and frogs are mating earlier [60]. In general, spring has come earlier at an average rate of 2.3 days over the last decades [61]. The phenological changes will likely affect community composition of ecosystem functioning [62]. Many species of birds, butterflies and amphibians have already shifted their distribution related to changes in climate [63]. Lawler et al. [35] stated that the redistribution of fauna resulting from climate change will create new ecological communities, new invasive species, and therefore will disrupt the functioning of ecosystems.

The further pressures on wetland biodiversity caused by invasive species and pathogens are a possible scenario. Increased air and water temperature combined with altered hydrological regimes will induce the growth of invasive species and expansion of diseases in the lower basin [64]. Rahel and Olden [65] argued that climate change increases the competitive ability of invasive species on natives and also increases the virulence of some diseases. Although changes in climate may be better or worse for specific local or exotic species, the overall change disturbs and stresses wetland habitats, making them easier to be invaded. Benning, LaPointe, Atkinson and Vitousek [66] conducted research in Hawaii and found that climate change will increase the probability of extinction of several bird species due to habitat loss, predation and avian malaria; and an increase of 2℃ will double the area infected by malaria and will cause the extinction of some bird species. With the projection of temperature and rainfall in Vietnam, biodiversity in Xuan Thuy Ramsar site will possibly affected by these mentioned threats.

3.4.3 Impacts of sea level rise on wetland ecosystems

Sea level rise is an important consequence of climate change. It is relevant for determining flooding, coastal erosion and the loss of flat coastal regions associated with climate change [8]. Rising sea level will cause a number of ecological effects in wetland ecosystems such as area reduction, saline intrusion, loss of biodiversity, and changes in agriculture and aquaculture [67].

Coastal wetlands in Vietnam are likely to be the most seriously affected by sea level rise

worldwide (Fig. 10). A sea level rise of 1 m means that 29% of wetland areas will be affected by seawater [68], making the Red River the most severely impacted area (Fig. 11).

Vietnam Ministry of Natural Resources and Environment (2012) predicted that with a sea level rise of 1 m, 10% of the total area of the Red River delta will be inundated, and 9% of the population living in the Red River delta will be affected [16]. The projected scenario will affect Xuan Thuy Ramsar site most because it is located in the lowest part of the river basin (Fig. 11).

As a consequence of sea level rise, there will be sea water intrusion into freshwater, thus increasing the salt concentration in the water and eventually damaging the stability of the wetland ecosystem. In the Red River system, saline intrusion into the inland water (freshwater) will expand more than 3 to 9 km from the sea-line by 2100 [48]. Research conducted by Hien, Quy, and Viet [69] found that salinity intrusion reaches 40 km in a direct line from the Red River mouth to inland areas, where intrusion raises salinity levels up more than 4‰ resulting crop yield decrease. Therefore the intrusion would destroy farming system in the Ramsar site.

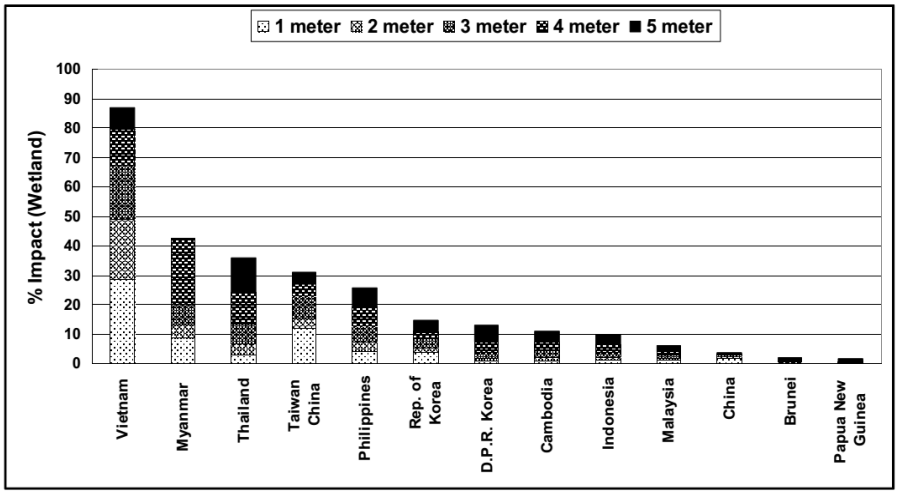

Fig. 10. Impact of sea level rise on wetlands of East Asian countries [68]

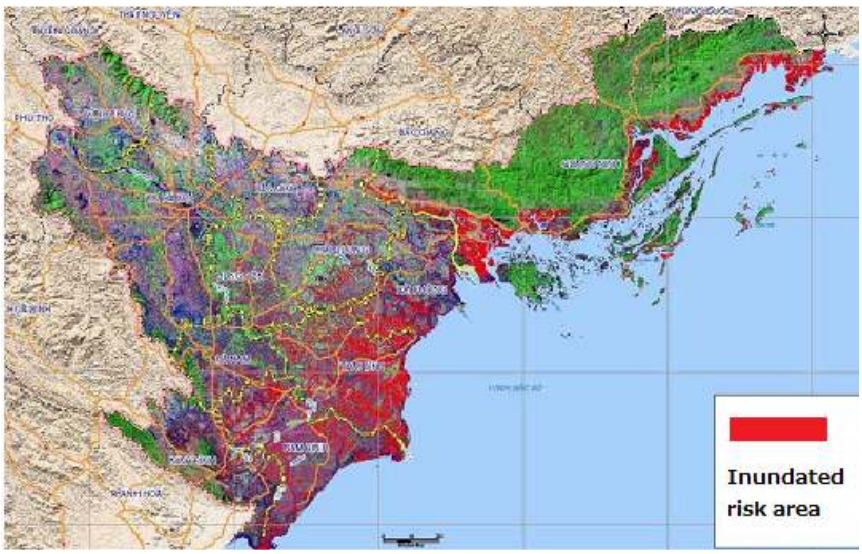

Fig. 11. Areas of the Red River delta at risk of being inundated in case of a 1 m sea level rise [16]

3.5 Responses

Responses are action chains taken by individuals, groups in society and government to prevent, reduce, adapt or compensate any component between drivers and impacts at different scales [70]. This paper identifies the responses by the Vietnamese government, and local communities within the Xuan Thuy Ramsar site in dealing with drivers, pressures, state and impacts associated with climate change and sustainable wetland management.

3.5.1 National responses

The government, acknowledging that Vietnam is one of the most seriously affected countries by climate change and sea level rise, has already implemented a dozen efforts, strategies, policies and plans to reduce greenhouse gas emissions and to contribute to the global efforts to mitigate climate change. For instance, the government ratified the Kyoto Protocol in 2002 as the first milestone of climate change mitigation commitment. Furthermore, the national target program responding to climate change (2008), the national climate change strategy (2011), the national action plan on climate change (2012), and Vietnam green growth strategy (VGGS) (2012) were issued and implemented in recent years. Importantly, VGGS has established specific targets on reducing the intensity of GHGs emissions by 8 - 10% by 2020 compared to the 2010 level. Thus, on a sector scale, the specific targets of GHGs reduction have also been established for main emission sources by 2020, including 8% from energy consumption, 5% from waste management, 20% from agriculture, and 20% from land use change and forest compared to the 2005 emission level [71]. On the carbon capture side the government is promoting the conservation and development of mangrove forest to increase carbon storage capacity of ecosystems, and thousands of hectares of mangrove forest have been planted and protected in Northeast Vietnam since 1994 [72]. All these policies emphasize that response to climate change is a key factor for the country's economy, and that GHGs emission reduction will be implemented along with economic development.

3.5.2 Local responses

Current conservation programs in Xuan Thuy Ramsar site have not involved climate change issues. Most programs focus on conserving the ecosystem and preventing impacts from human activity and economic development. For instance, local governments have made efforts to improve community awareness of the importance of natural resources and environmental conservation. As a result, most local people living in the buffer zone have participated or been involved in local associations regarding wetland ecosystem protection. However, climate change and sea level rise are new challenges for community awareness because local people have little understanding of climate change and its impacts [15].

Recently, the most successful program for natural resource conservation in Xuan Thuy is a community based ecotourism model. This model aims to strengthen the capacity of local stakeholders by involving them in the development and implementation of ecotourism services [14]. This program brings many short-term benefits to local people, especially poor women and fishermen. Positive effects such as decreased illegal natural resource exploitation, increased income and local awareness on wetland protection have been recorded [15]. However, long-term wetland conservation may be affected if this ecotourism are not managed well. Besides, the local government is planning to develop eco-agriculture and eco-aquaculture that can help to protect wetland ecosystem sustainably in the Xuan Thuy Ramsar site [15].

3.6 Discussion

Climate change happens on global scale, but its impacts on ecosystems are local and vary from region to region. The analysis obtained from the DPSIR framework has shown that climate change will be considerable challenge for long-term wetland conservation in Xuan Thuy Ramsar site.

Because it is located in an estuarine area, the Ramsar site is directly affected by sea level rise, thus, the loss of wetland area is likely to be the most serious concern. Rising sea level results in the inundation of wetlands, which temporarily can bring more nutrients, but if continued it can damage traditional habitats. Moreover, inundation can create new conditions that facilitate the growth of invasive species and disturb the ecological niche of native species. On the other hand, extreme weather events originated in the ocean have caused serious changes and even destruction of coastal wetland

systems, resulting in sudden changes in habitats and ecological structures.

Changes in temperature and rainfall have strong impacts on wetland ecosystems. These two factors are the basis of species distribution. Most species are able to adapt slowly to natural changes over millions of years of evolution, however, the sudden and dramatic changes we are facing today exceed the adaptive capacity of species and communities [73]. Consequently, the extinction of a single species can negatively disturb a whole ecosystem because species are connected through food webs and complex interaction mechanism.

Shifts in phenology due to climate change are also considerable impacts on wetland ecosystems. Although it remains difficult to interpret phenological shifts and to explain the variation among species, and even among population within species, it has been documented in numerous recent studies that global climate change has significantly influenced the timing of species' growth such as the timing of plant and animal reproduction [74,75,76,77]. These changes in phenology affect seasonal behavior and interaction between species living in ecosystems. Although natural evolution can help some species to adapt to these changes, some others species cannot successfully adapt and will be significantly affected.

Finally, the impact of human development exacerbates the vulnerability of wetland ecosystems because they are likely to be isolated by dams, dykes, roads and other infrastructure that prevent wetland species from migrating in response to changes in water level and temperature. Therefore, although our investigation focuses on the impacts of climate change it is impossible to ignore the effects of human activities when planning for wetland conservation

4. CONCLUSION

This paper has identified and analyzed the challenges of climate change for sustainable wetland management in a typical coastal protected wetland - the Xuan Thuy Ramsar site in Vietnam. It is evident that climate change and its consequences can increase pressures and aggravate changes in wetland ecosystems. The potential consequences of an increase in further GHGs emission are still not fully explored, but further temperature increase, changes of rainfall, rising sea level, and more frequent extreme weather events are predicted. These factors raise the risks of ecological changes and the vulnerability of wetlands. The state and property of ecosystem in Xuan Thuy has shown that climate change together with human activity will cause considerable negative effects on the natural resources and biodiversity of this Ramsar site.

The location of such protected areas are fixed, but the environmental elements within them may change, especially due to climate change [78]. In addition, the driving forces come not only from the study site, but also from regional and global influences. Therefore, more responses (adaptation and mitigation) and efforts are necessary to maintain wetland ecosystem; and climate change needs to be integrated into a strategy of wetland management. Our review suggests that a long-term conservation plan that includes climate change is crucial for sustainable management of Xuan Thuy Ramsar site. Although many potential changes to coastal wetland associated with climate change were illustrated here, further studies on the impacts of climate change on Xuan Thuy Ramsar site are necessary to develop an appropriate conservation plan.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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