Climate Change Vulnerability Assessment for the Major Habitats and Species in Lung Ngoc Hoang Nature Reserve, Vietnamese Mekong Delta

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ABSTRACT

The study assessed the vulnerability of habitats and species to climate change in Lung Ngoc Hoang Nature Reserve (NR), Vietnam. The vulnerability assessment tools for habitat and species were developed by the International Union for Conservation of Nature (IUCN). Community members, NR managers and experts in the fields of environment, economic and rural development were involved in this study. The results showed that saltwater intrusion and inundation could cause serious threats to habitats (i.e., open water, Lung, agricultural and Melaleuca habitats) and freshwater species. The combined impacts of drought and high temperature potentially increase forest fires for the Melaleuca habitat and decrease the quantity and quality of open water habitats. The Melaleuca and Lung habitats have a high baseline conservation status, in which Melaleuca habitats are more vulnerable than Lung habitats. Conversely, open water and agricultural habitats are at low baseline conservation status, but open water habitats are more vulnerable. In addition, the proliferation of invasive alien species, encroachment on agricultural cultivation, and the degradation of water quality are also great threats to the NR. Key species, including *Melaleuca cajuputi*, *Elaeocarpus hygrophilus*, *Chitala ornate*, *Channa micropeltes*, were at low threat of climate change. However, *C. ornate* and *C. micropeltes* are seriously endangered by seawater intrusion, drought and poor water quality. The findings of this study can provide essential information for NR managers to formulate water management plans for the protection and management of the habitats and species in Lung Ngoc Hoang NR.

1. INTRODUCTION

The frequency of impacts caused by climate change has continuously increased from the late 19th century onwards (Khalid et al., 2021). It is even more serious since the distribution of these risks is uneven around the world, which depends on the characteristics of each region. For example, these can be geographic features, warming rates, development levels, vulnerability, adaptation, and mitigation strategies (Lee and Choi, 2018). Wetlands are internationally recognized for providing different services to humans and other living organisms (Tiner, 2014; Ricaurte et al., 2017). However, it is also deemed to be very vulnerable to climate change (Kelleway et al., 2017; Duncan et al., 2021). Lung Ngoc Hoang Nature Reserve (NR), also referred to as Lung Ngoc Hoang wetland, is located on low-lying land, with typical topography of the southern Hau River, Vietnam. Lung Ngoc Hoang NR, one of the green lungs in the Mekong Delta, has an important role in biodiversity conservation (Duong and Frederick, 2017). This wetland is well known for its untouched melaleuca forest ecosystem, which provides a favorable habitat for a wide range of indigenous fauna and flora. Consequently, this biodiversity also kindly supports local livelihoods.

However, the usage of canals to serve the fire prevention policy has directly affected the natural water circulation in the NR. Once the NR opens the sluice, the water level is low. At the end of the rainy season, the sluice will be closed to store water. This action has facilitated leaf decomposition in anaerobic conditions, which has caused black and polluted water canals. As a result, the deterioration of water quality

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will influence aquatic biodiversity. In addition, the NR is situated in the center of the Mekong Delta and the transition zone between the tidal currents of the East Sea and West Sea. Due to this special location and the effects of the Mekong River, the NR accumulates many pollutants and is also very sensitive to climate change (Hau Giang Department of Natural Resources and Environment) (Hau Giang DoNRE, 2021). Therefore, any development and plans of the province and neighboring provinces/cities (especially, Can Tho, Kien Giang and Soc Trang Provinces) can cause an array of consequences on the biodiversity and ecosystem of Lung Ngoc Hoang NR, which in turn affects local livelihoods. The sensitivity of the NR was even more enhanced by the establishment of large sluice gates on Cai Lon and Cai Be Rivers. The sluices were installed in 2017 to prevent increased salinity from the West Sea, which has changed the dynamic hydrological regime of Lung Ngoc Hoang NR to a static one. This change has caused water pollution due to an increase in agricultural and aquacultural runoff, industrial and urban waste, and an intensive invasion of alien species like water hyacinth.

Water is no longer circulated inside the NR in the end of the rainy season to dry season, leading to extremely low dissolved oxygen levels in the water bodies. It is necessary to develop a comprehensive management plan for Lung Ngoc Hoang NR that can alleviate the impacts of climate change and dam development on the environment and biodiversity of the area. The main objectives of this study were to assess the vulnerability of ecosystems, including major habitats and key species, to climate change in Lung Ngoc Hoang NR.

2. METHODOLOGY

2.1 Site description

Lung Ngoc Hoang NR, located in Phung Hiep District, Hau Giang Province, Vietnam, was established under the Prime Minister's Decision No. 13/2002/QD-TTg dated 14 January 2002 (The Prime Minister of Government, 2002). Lung Ngoc Hoang is situated in a network of national special-use forests. The NR's activities comply with the Government Decree No. 117/2010/ND-CP from 24 December 2010 on the organization and management of a system of national special-use forests (Vietnamese Government, 2010). The NR is located between latitudes 09°04′ to 09°45′ North and longitudes 105°39′ to 105°43′ East, with a total area of 2,799.97 ha (Forestry Research Institute, 2021), as presented in Figure 1. This area was formed during the sea recession and alluvial deposition. It mainly consists of coastal sediments and swamps, forming a low and fairly flat terrain, with an average elevation varying from 0.30 m to 1.50 m. The region has an open canal system through low-lying areas, such as Lai Hieu canal and Hau Giang 3 canal, connecting Lung Ngoc Hoang NR with adjacent areas. The system connects with Cai Lon and Cai Tau Rivers, which drain to the West Sea (Gulf of Thailand); and Sang Bo canal, Chu Ba and Xeo Xu canals emptying into Quan Lo-Phung Hiep Canal, connecting with the East Sea and the Ca Mau peninsula. Due to the interlaced canal system and geographic location, the hydrological regime is influenced by the intra-provincial rainfall regime, the flood zone of the Hau River, and the high tides of the East Sea and the West Sea. Sub-zones and plots in the NR are separated by a system of canals to facilitate commute and prevent forest fires. This area has freshwater all year round, although it has recently experienced slight saltwater intrusion. The average water level is 0.40 m, which increases to 1.1 m during the flood season and is less than 0.20 m during the dry season. The annual rainy season in Hau Giang begins in August and lasts for about five months, with the peak in October and November often coinciding with a period of locally heavy rain. Heavy rain and high tide occur simultaneously, increasing the water level and causing flooding in a large area over prolonged periods in the rainy season.

The reserve is located in the low-latitude belt of Vietnam, influenced by the tropical monsoon climate regime. The average annual temperature is 26.6°C, with an average relative humidity of 85%. There are two monsoon seasons in the year, including the northeast monsoon (from October to April) and the southwest monsoon (from May to November). The average rainfall in the NR is 1,700-1,800 mm/year, with the average number of rainy days per year varying from 120 to 135 days. These climate data were recorded at Vi Thanh hydro-meteorological station, Hau Giang Province, Vietnam (105°27′42″E, 9°49′04″E).

2.2 Vulnerability assessment

The Climate Change Vulnerability Assessment methodology employed in this study was developed by IUCN under the Mekong WET project (IUCN, 2017). The methodology focuses on participatory assessment and discussion with the community and local, regional and national authorities responsible for

site management. The vulnerability assessment was carried out using two tools in an excel spreadsheet: a vulnerability assessment tool for habitat and a vulnerability assessment tool for species. To evaluate in the most general and objective way, a research team consisted of researchers with expertise in environment, economics and rural development, community members surrounding the NR (both male and female) and site managers. The study was conducted through field data collection and interviews in May 2021 in Lung Ngoc Hoang NR and the surrounding residential areas.

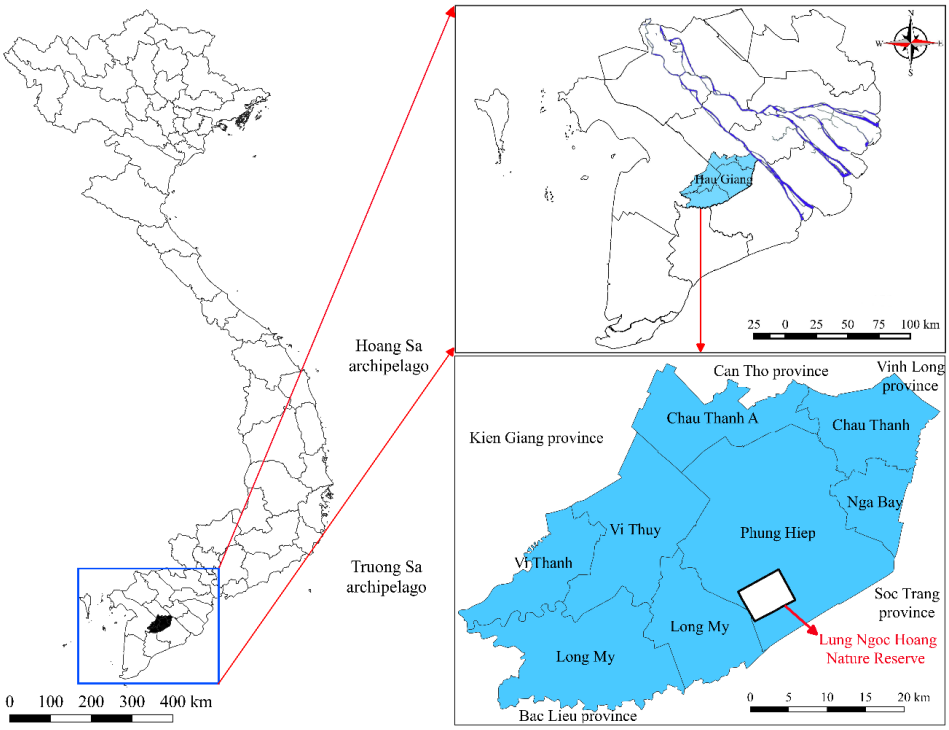

Figure 1. Location map of Lung Ngoc Hoang Nature Reserve, Hau Giang Province, Viet Nam

After consulting with managers at the NR and a group of experts (Table S1), the research team selected melaleuca, open water, agricultural land habitats (artificial habitat) and Lung habitats (natural habitats with the domination of grasslands). Besides that, four species were selected for climate vulnerability assessment, including two plant species (*Melaleuca cajuputi* and *Elaeocarpus hygrophilus*) and two fish species (bronze featherback (*Chitala ornate)* and the giant snakehead (*Channa micropeltes*). These are the main habitats and species representing a majority of the NR.

To evaluate the vulnerability of habitats and species, the research team and site managers assessed the baseline conservation status of the selected habitats and species. The next step was to project climate change impacts to 2050 based on NR or regional documents to address climate change threats to wetlands. These habitats and species were then appraised for their vulnerability to climate change (Table 1). Finally, potential threats to each habitat and species were identified by determining exposure, sensitivity, and adaptability to climate change. An average score of the factors (exposure, sensitivity and adaptability) represents the climate change vulnerability as a whole. In addition, the confidence score of the vulnerability assessment is also determined based on Table S2.

Table 1. Classification of climate change vulnerability

Climate change vulnerability	Category intervals
Very high	2.7-3.0
High	2.3-2.6
Moderate	1.9-2.2
Low	1.5-1.8
Very low	1.0-1.4

3. RESULTS AND DISCUSSION

3.1 Vulnerability of the habitats

The vulnerability assessment of each habitat is presented in Figure 2. In general, melaleuca habitats can be identified as the vulnerable habitats to climate

change, followed by the open water habitats. However, the melaleuca habitats have a higher conservation status than the open water habitats. The vulnerability of Lung and agricultural habitats is observed to be lower. Lung habitats are given high conservation status because they host a number of important species like the giant snakehead.

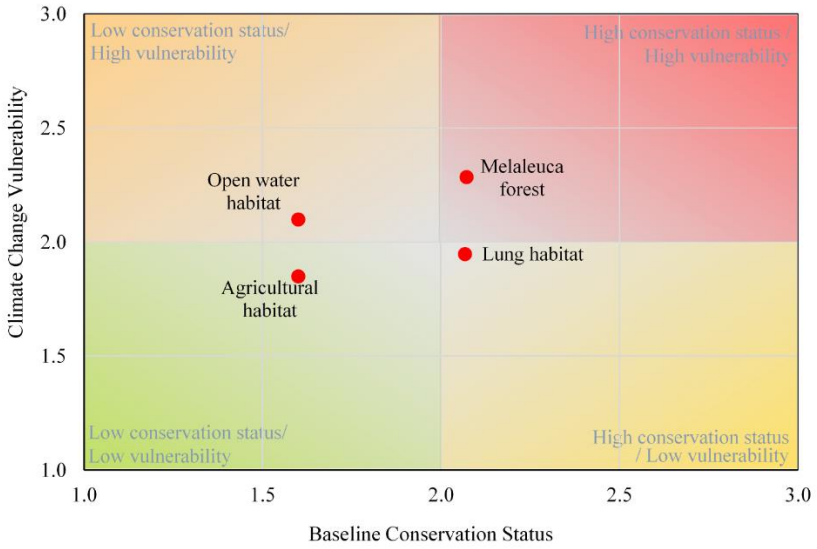

Figure 2. Current status of conservation and vulnerability to climate change in NR

3.1.1 Melaleuca forest habitat

In the NR, the melaleuca forest habitat is the most dominant (Table 2). It is protected and re-forested, covering more than 50% of the total wetland area. However, due to households encroaching on adjacent forest land for production, the forest area has decreased over the past 50 years. This is a threat in most protected areas in the Mekong Delta (Triet et al., 2019a).

The Melaleuca forest habitat does not host a diversity of plant species because of frequent flooding and high soil acidity (pH=4.53-5.65) (Hoa, 2015). Melaleuca trees (*Melaleuca cajuputi*) are the dominant species in the upper layer and other plant species (*Phragmites vallatoria* and *Stenochlaena palustris* with high densities of 4.56 and 2.11 tree/m^2, respectively) (Ni, 2018). According to Odum (2005), tropical plantations also have a low species composition. The melaleuca forest habitat reserve has a high economic value since locals can exploit wild forest honey. The melaleuca forest habitat can tolerate flooding to a moderate extent, but it is vulnerable to drought and fire. Therefore, the management board of Lung Ngoc Hoang NR always maintains a high water level to prevent fire. This control approach is likely to threaten other biodiversity and degrade water quality in the future due to the breakdown of organic matter in flooded environments and very little exchange of water with external bodies of water. Consequently, the Melaleuca forest habitat was determined to have a high conservation value and a baseline conversation rating of 2.1 (Figure 2). Besides the results of the baseline conservation status assessment, this was also reflected in the habitat's fire prevention plans in the dry season.

Table 2. The features of the habitats in Lung Ngoc Hoang Nature Reserve

Habitats	Area (ha)	Dominant species
Melaleuca forest	1482.70	*M. cajuputi*, *Phragmites vallatoria*, *Stenochlaena palustris*
Lung habitat	310.35	*Eupatorium odoratum*, *Cyclosorus parasiticus*, *Nypa fruticans*, and other vines.
Agricultural land	767.16	Rice, pineapple, lotus, fruit trees, and vegetables
Open water	182.44	*Eichhornia crassipes*, *Azolla pinnata*, *Pistia stratoides*, *Nymphaea rubra*, Lotus and several species of fish belong to families such as Channidae, Toxonidae, Loricariidae, Cobitidae, Hemiramphidae, Aplocheilidae
Others	57.32	The dominant species belong to families such as Asteraceae, Malvaceae, Fabaceae, Cactaceae commercially valuable species such as *Artocarpus heterophyllus*, *Durio zibethinus*, *Annona muricata*, *Musa paradisiaca*

Under climate change, survey results have shown that the Melaleuca forest habitat is most affected by drought and high temperatures (Table 3). In addition, prolonged flooding negatively impacts the existence and growth of species living in the habitat, which has been affected by rising water levels and heavy rainfall. The habitat is also vulnerable to extreme weather events, such as storms and high winds, which can topple and damage trees. Sea level rise and saltwater intrusion also threaten the Melaleuca forest habitats, with increased saltwater intrusion expected to impact the Mekong Delta, which the IPCC report predicts is one of the three most vulnerable coastal regions in the world (Nicholls et al., 2007). The Melaleuca habitat is moderately susceptible to drought, rising temperature and sea level. However, the ability of this habitat to adapt to new conditions in the context of climate change is assessed at a relatively high level (Table 2). The Melaleuca forest habitat was assessed to be highly vulnerable to the impacts of climate change, with a score of 2.3 (Figure 2). The results of vulnerability for Melaleuca forest habitat were similar to the other wetlands in the Mekong Delta area, including Phu My conservation area (score 2.4), U Minh Thuong National Park (score 2.0) (Triet et al., 2019a; Triet et al., 2019b).

3.1.2 Lung habitat

Lung habitat is the local term used to define areas of lowland topography where wetland grasslands are dominant all year round. This habitat accounted for approximately 11.08% of the total reserve area, as presented in (Table 2). The area has remained mostly unchanged thus far, except for the expanding grassland area. This expansion has led to dredging around the border edge to create a path for boats around the Lung habitat to support the tourism development. The Lung habitat plays an important role in maintaining fish stocks by providing habitat and spawning grounds for various fish and other species. The layers of thick vegetation make an ideal shelter and breeding ground for many reptiles, amphibians, and insects and provide habitats for birds. The area has highly diverse vegetation with supporting species (Table 2). The area is strictly managed and protected in the core zone of the NR where the anthropogenic impacts are limited. Nevertheless, this cannot prevent the invasion of many exotic species that can diminish habitat diversity and be a major threat to fish. As a freshwater wetland, the habitat is significantly affected by the saline intrusion. Lung habitat recovers relatively quickly from extreme weather events but requires frequent flooding to regenerate; therefore, this habitat cannot withstand drought. Overall, the initial conservation status is just above average (score 2.1) (Figure 2), reflecting both positive and negative impacts on habitat features.

Under climate change, the Lung habitat is vulnerable to drought, high temperatures, hydrological changes, saline intrusion, and high flooding (Table 3), which can lead to a loss of habitats for plants and animals and breeding grounds for fish species. Lung habitat areas are the most susceptible to drought and hydrological changes due to changes in flood regimes caused by anthropogenic factors combined with climate change. In addition, because this is a wetland area, floods or prolonged rain often lead to inundation and mass deaths of plants and animals. Lung habitats can adapt and recover from changes in rainfall and flooding. However, there is not ample area for the habitat to expand due to grey infrastructures such as dikes, canals, and embankments. Thus, extreme weather can cause temporary disturbances but is not expected to cause permanent damage to the habitat. The vulnerability of this habitat to the impacts of climate change (score 1.9) was lower than the Melaleuca habitat (score 2.3) (Figure 2).

3.1.3 Open water habitat

Open water habitat covers all water bodies and canals in Lung Ngoc Hoang NR. Its area is approximately 182.44 ha, accounting for about 6.42% of the total NR area. The area has recently increased because these canals have become wider and deeper by NR activities and natural landslides on the banks. In the baseline vulnerability analysis, the habitat is characterized by a high diversity of aquatic plants, especially a high proportion of exotic species. The habitat integrity is threatened by invasive alien plants, although the management manually removes these species each year. In addition, water pollution from the melaleuca habitat and agricultural production threatens open water habitats. The vulnerability analysis showed a low baseline conservation status of 1.6 (Figure 2). Although this habitat has a low conservation level and is not currently in danger, it is considered a critically important habitat in the NR because it is the main water source for local people in domestic and agricultural activities and other creatures in this study area.

An assessment of habitat exposure, sensitivity and adaptability revealed that the open water habitat is highly vulnerable to climate change (Table 3).

Table 3. Summary of key climate issues in the habitats of Lung Ngoc Hoang Nature Reserve

Habitats	Climate issues	Exposure level	Sensitivity level	Adaptivity
Lung	Drought, high temperature, saltwater intrusion, hydrological change, flood	Average	High	High
Melaleuca forest	Drought, high temperature, sea-level rise, flood, hydrological change, storms and high wind	Average	Average	High
Open water	Drought, high temperature, saltwater intrusion, hydrological change	High	High	Average
Agriculture	Floods, droughts, other extreme weather events (early rain, storms), saltwater intrusion	Low	Average	High

Hydrological changes and saltwater intrusion are the two most pressing threats. Moreover, the habitat is also at risk from heavy rainfall and high temperatures. The impacts of saline intrusion were visible in 2017-2018 when the salinity levels at the site reached 0.8‰, leading to some trees shriveling and losing their leaves. However, the system was otherwise able to withstand this level of salinity. The site also saw changes in hydrological conditions through extreme weather events at the beginning of the rainy season in 2021. Locals reported prolonged and heavy rainfall and a complete lack of a dry period have led to waterlogged conditions. Increased rainfall also led to impacts on water quality through increased erosion and sediment accumulation. Higher temperature is expected to reduce dissolved oxygen concentration, leading to decreased respiration capacity for freshwater species, especially white fish (*Chitala ornate*, *Barbonymus gonionotus*, *Parachela siamensis*, *Corica laciniata*, etc.). An increase in water temperature will also affect the survival of aquatic organisms if it exceeds their heat tolerance. The open water and Lung habitats mainly have aquatic plants and vines, which are able to regenerate after weather events much more quickly than Melaleuca forest habitats, dominated by thick trees that need a recovery period. Open water habitats are vulnerable to dry season impacts, with increased evaporation due to higher temperatures and severe droughts that can lower water levels and reduce habitat for aquatic animals. These consequences can lead to changes in the flora and fauna composition in the habitat. Overall, open water habitats were identified as having a high vulnerability (score of 2.1) (Figure 2) to the combined effects of climate change, especially in the dry season. The previous study by Scott et al. (2018), Triet et al. (2019a) and Ly et al. (2019) also evaluated high vulnerability for open water habitats, ranging from 2.1-2.4.

3.1.4 Agricultural habitat

Agricultural habitats, including the areas for agricultural production, such as rice, perennial crops, and other annual crops, are significantly impacted by human activities. These habitats are assessed as having a low baseline conservation level (score around 1.6) (Figure 2), which is lower than Boeung Prek Lapov protected landscape (score 1.7) (Ly et al., 2019). This disparity is explained by the degree of contribution to livelihoods and the influence of objective factors such as externalities. During the last five years, the agricultural habitat has increased, with an area of about 767.16 ha, accounting for 27.40% of the total area. Agricultural habitats are quite common in the Mekong Delta, and the agricultural land area tends to increase near protected areas (Triet et al., 2019a). This may partly explain the baseline conservation value of the habitat. The agricultural habitat contains the most economic species. According to a report by Ni (2018), there are about 156 species of higher plants in agricultural habitats at the site. The main exploited species are rice, pineapple, lotus, fruit trees, and vegetables. In addition, some households take advantage of the vacant space to raise livestock and poultry and use canals to raise fish and grow vegetables. This habitat is often disturbed, affecting plant species through chemical spraying and land reclamation activities. This can add nutrients to the soil and limit the development of pests and diseases to save costs and bring high efficiency in production. Agricultural habitats are also vulnerable to prolonged rains and floods. Alien species are also present in agricultural habitats, though occurring in low densities, and therefore presenting a relatively lower threat than in Lung and open water habitats.

The survey results indicated that the vulnerability of the agricultural habitat to the impacts of climate change is low, with major threats including

floods, droughts, and other extreme weather events such as early rains and storms. Although flooding can cause damage to the crops, people can take advantage of the floods to diversify their livelihoods and increase their incomes by catching fish, farming fish and growing snails. Floods also help them improve the land quality by washing away pests and diseases from rice cultivation and providing nutrients to the soil. High temperature and heavy rain affect crop productivity and lead to economic losses in the area (Van et al., 2021). Agricultural habitats are most affected by climate change impacts from April to May due to the highest temperature of the year with saltwater intrusion (Hau Giang DoNRE, 2021). According to Trinh et al. (2021) and Van et al. (2021), climate change, such as the high temperature, earlier rainfall, and sea-level rise, is forecast to significantly impact agriculture in Vietnam (MoNRE, 2016). Overall, agricultural habitat is adaptable to the predicted extreme weather and climate conditions because it is expected that farmed plant and animal species can be adjusted to suit new climatic conditions. Therefore, the agricultural habitat is assessed as having a low vulnerability to climate change (score of about 1.6) (Figure 2). It is supported by Ly et al. (2019) that suggested that rice fields have low climate change vulnerability (score 1.9).

The main threats to these habitats arise from large-scale hydrological changes and pollution caused by the accumulation, extraction, and diversion of river flows for agriculture, industry and hydroelectricity. Furthermore, agricultural encroachment and invasive alien species considerably increase pressure on all four habitats. In the future, the habitats in Lung Ngoc Hoang NR will be susceptible to saltwater intrusion and flooding due to sea-level rise, as predicted by 2100. Since this is a seasonal freshwater wetland, saltwater and permanent flooding will far exceed the capacity of the habitats.

3.2. Vulnerability of species

The reasons for choosing these species are presented in Table 4. Lung Ngoc Hoang NR is known as the cradle of freshwater fishes where they gather to lay eggs during the breeding season in the west of Hau River. This area acts as a buffer zone that connects Long Xuyen Quadrangle with Ca Mau peninsula. According to previous studies conducted by the Management Board of the NR, the number of *C. ornate* and *C.micropeltes* have recently increased. *C. ornate* and *C. micropeltes* are also on the List of Rare and Precious Species in Vietnam that need to be protected and restored (MoARD, 2019).

Table 4. Rationale for choosing the evaluation species

Species	Reason for evaluation
Melaleuca *(M.cajuputi)*	Typical species, abundant in the reserve
Elaeocarpus (*E. hygrophilus*)	Investment in additional planting, large area, listed in the Red Book of Vietnam
Bronze featherback (*C. ornate*)	Large numbers, representative of fish populations in the area, on the List of Rare and Precious Species
Giant snakehead (*C. micropeltes*)	Large numbers but rare elsewhere in the Mekong Delta, representing fish populations in the region, on the List of Rare and Precious Species

3.2.1 Melaleuca cajuputi

M. cajuputi, the most dominant species of Melaleuca in the world, is also a typical and dominant forest tree species in the acid sulfate soil wetlands of the Mekong Delta. All *M. cajuputi* in the NR are planted without the existence of the natural one, which is a unique feature of this NR from other protected areas and national parks. The *M. cajuputi* in the study area are less than 10 years old and have a trunk height between 6.78-12.40 m and a diameter between 8.75-10.67 cm. Those over 10 years old have a height of 11.12-14.68 m and a diameter of 11.61-16.63 cm. The total wood reserve of Lung Ngoc Hoang NR is about 187,351.5 m^3.

M. cajuputi can reproduce quickly and have a large dispersal range because of their small seeds and large annual seed production. In terms of the baseline conservation status, *M. cajuputi* can tolerate prolonged waterlogging but still require drying time to ensure optimal growth. Permanent waterlogging leads to poor growth and inhibits natural regeneration. Although they are freshwater species, they can tolerate low salinity for short periods. While some trees were planted before the establishment of the NR, such as in 1984 and 1994-2002, others were planted later in 2006 and 2015. The trees have been grown in favorable conditions with rarely negative impacts, thus having a high density of 4,000-5,100 trees/ha. The annual water

storage to prevent bushfires in the dry season has negatively affected the growth of *M. cajuputi*. In addition to the threat of prolonged flooding, some high-grade melaleuca trees in strictly protected areas cannot be assisted by silviculture like thinning and cleaning forest. Analysis of *M. cajuputi* in the NR yielded a baseline conservation score of 1.7, with a confidence level of 2.7 (Figure 3).

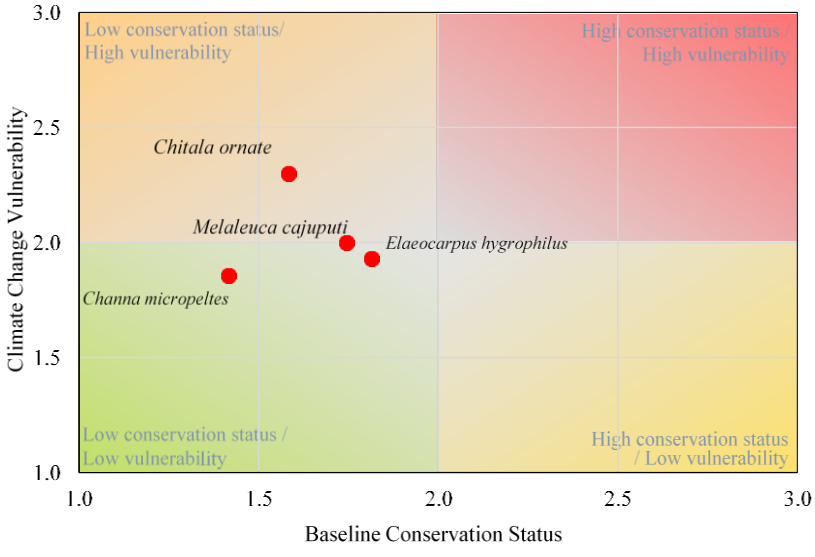

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Figure 3. Basic conservation status and vulnerability of species

In terms of the vulnerability assessment to climate change, the results showed that saline intrusion would threaten the survival and development of mature *M. cajuputi*. The impacts of climate change are expected to influence seeds and seedlings of the tree disproportionately. Thanks to a wide canopy of mature melaleuca trees, the plants growing under have suffered fewer impacts from climate change. Many studies have reported that melaleuca trees can tolerate various extreme conditions such as floods, droughts, and mild saline conditions (Cuong et al., 2004; Tanaka et al., 2011; Tran et al., 2013). Besides, their distribution in various environments is also testament to their great adaptability to different climates. Mature *M. cajuputi* and seedlings can develop suckers from their roots, which helps them resist flooding. Wetlands are one of the most affected by climate change (IPCC, 2007), but melaleuca species are well adapted to inundation conditions (Cuong et al., 2004; Tran et al., 2013). According to Tran et al. (2013), *M. cajuputi* can also survive a shift to a colder and drier climate. Due to these aforementioned features, Melaleuca species possesses a remarkable potential to regenerate. Besides seeds, *M. cajuputi* can regenerate by shoot or clone-regeneration. *M. cajuputi* has an average exposure to climate change with high tolerance and adaptability. The vulnerability assessment to climate change ranked melaleuca (*M. cajuputi*) in the group of moderate vulnerability, with a score of 2.0 at a confidence level of 2.5 (Figure 3). According Triet et al. (2019a), Triet et al. (2019b) and Triet et al. (2019c) showed that *M. cajuputi* are highly vulnerable in U Minh Thuong national park, Phu My species-habitats conservation area, and Lang Sen wetland reserve, respectively. One of the reasons for this difference is due to the characteristics of the soil environment, the conservation level of the area, and the geographical location.

3.2.2 Elaeocarpus hygrophilus

Elaeocarpus (*E. hygrophilus*) is a species in the Elaeocarpaceae family. It is a medium-sized evergreen tree, about 10-15 m height, with white wood and a thornless trunk and branches. The tree bears olive-colored, smooth, oval-shaped fruits with two pointed ends, measuring 3-3.5 cm long and 1.5-2 cm wide, with one seed per fruit (Figure 4). The Elaeocarpus trees are located along the canals and on the degraded acid sulfate soil. Due to their low economic value, they only grow in a limited potential area with favorable ecological conditions. This species is on the Viet Nam Red List. In 2007, the management board of the NR planted more than 10,000 Elaeocarpus trees. These planted trees were propagated from other native trees and planted from Elaeocarpus seeds. Thus, the quantity and the area of trees have been greatly increased thanks to these effective conservation measures.

Figure 4. Elaeocarpus (*E. hygrophilus*)

Elaeocarpus, a canopy tree, requires a spacious place to grow well. Thus, once planted in a dense forest area, the tree often grows slowly and reaches high but is unable to create a canopy. The trees in the study area often suffer from pests and diseases, which has resulted in a decrease in *E. hygrophilus* biomass. Although the percentage of seedlings from seeds is very high, they have to compete for light with other species; thus, seedlings frequently fail. The dispersal rate depends on the water flow and the space availability for the tree to drop seeds. In the current conditions, the seed dispersal capacity of the tree is about average. Mature trees can withstand flooding and are moderately resilient to drought. The seeds are covered with hard shells, which has facilitated their recovery from droughts and floods. The main threats to *E. hygrophilus* in the NR include pests and diseases and a lack of suitable habitat. The analysis recorded a baseline conservation score of about 1.8 that was higher than melaleuca (Figure 3). This species is likely to be affected by floods, droughts, and salinity intrusion in the future, based on the forecast until 2100 from the MoNRE (2016). The species habitat is mostly in canals and ditches; thus, they can survive in similar habitats in other areas without being inhibited by changes in climatic factors. *E. hygrophilus* was determined to have a moderate level of vulnerability to climate change in the NR (score 1.8, confidence level 3.0) (Figure 3). When subjected to the direct pressures of climate change, this species can remain relatively ecologically connected.

3.2.3 Bronze featherback

Lung Ngoc Hoang NR is known as the "fish navel" of the Mekong Delta. The bronze featherback (*C. ornate*) (Figure 5) is a typical species in this area with a well-developed population. The assessments have observed an increasing yield with a high commercial value. The fish usually live alone and then gather to spawn once a year. They are highly fertile and often spawn in tree holes, where there is the shade of trees on the open water. Invasive weeds in the Lung habitat interfere with this reproduction. Persistent rain and subsequent black water from the melaleuca forest habitat have caused slow growth or even death of the fish. According to the managers, there are other reasons for the death of fish, such as climate change (high temperature and saline intrusion) and the residues of pesticides. However, these topics need further investigation. Habitat degradation and local fishing are the main threats to bronze featherback. They are also preyed upon by birds and other fishes within the NR, such as *Anhinga melanogaster* and *Channa striata*, and their juveniles are especially vulnerable because they live near the surface of the water.

Figure 5. Bronze featherback (*C. ornate*)

Climate change can cause certain impacts on the species survival. Droughts are considered moderate threats, but the consequences of long-term hydrological changes are assessed to be more significant to their habitat. The presence of the Cai Lon-Cai Be dam will lead to a change in the hydrological regime, namely less seasonal variation in water flow and level. In addition, the water management regime in the NR may affect water quality, which exceeds the tolerance of the species. Inundation due to sea-level rise can also reduce the reproduction ratio by narrowing suitable habitats. As a freshwater fish, the *C. ornate* may also be threatened by the saline intrusion, as predicted by the MoNRE (2016) and Triet et al. (2019b). If the sea level rises according to the forecast, by 2100, the habitat of the bronze featherback is likely to be completely lost in the Lung Ngoc Hoang NR. The vulnerability of *C. ornate* is classified as highly vulnerable (score 2.3) with a confidence level of 3.1 (Figure 3); this was similar to the study of Triet et al. (2019a) at U Minh Thuong National Park (score 2.2). This can be explained by the

similarity of geographical conditions (wetland areas) and large populations but not as abundant elsewhere in the Mekong Delta.

3.2.4 Giant snakehead

The giant snakehead (*C. micropeltes*) is a highly important economic fish and is listed as a protected species in the list of inland freshwater protected areas of Viet Nam (Figure 6) (The Prime Minister of Government, 2008). Thus, fishing the *C. micropeltes* within the NR is prohibited. The fish is found in several protected areas and is currently assessed as a species of least concern (LC) (Allen and Ng, 2020). According to the officials at the NR, the *C. micropeltes* have high reproduction rates, but the number of individuals is lower than that of the bronze featherback. This may be because, during the period of low water levels, the *C. micropeltes* move out of the forest. The giant snakehead fish is a large fish, preying on other fish and feeding on each other if there is a lack of food. Therefore, they require a large habitat, and areas with high densities of *C. micropeltes* are less likely to have other fish species. The distribution characteristics revealed that most live in inland slow-flowing or still freshwater bodies such as rivers, lakes, canals, ponds, and lagoons (Rainboth, 1996; ICEM, 2013). They breed and raise their juveniles in stagnant water 30-100 cm deep and around 27°C (ICEM, 2013). *C. micropeltes* are resilient because the spawning cycle is short, from April to June per year. Due to their high economic value, giant snakehead fish are facing with threats from fishing, especially people from outside the NR. The basic conservation status of *C. micropeltes* is 1.4, a low level (Figure 3).

(a) (b)

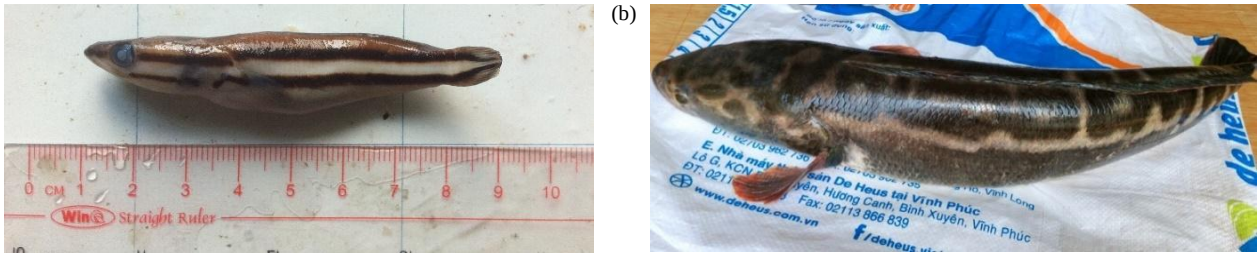

Figure 6. (a) A juvenile giant snakehead, (b) An adult giant snakehead (*C. micropeltes*)

Climate change threatens to have moderate impacts on the development and survival of the *C. micropeltes*. The species spawns in stagnant areas where flooding can reduce the availability of suitable habitats for spawning. However, *C. micropeltes* are tolerant of high water pollution and low pH and can withstand the effects of drought, prolonged rain, and changes in hydrology. Furthermore, the species has a low vulnerability to rising temperatures because the expected temperature rise in the area is within the tolerance range (7-35°C). They can survive in freshwater and brackish water; therefore, seawater intrusion may have only a moderate impact. In addition, the young *C. micropeltes* is known to migrate over short distances on land to find other water bodies, using its ability to breathe air (Pijper, 2021), which allows it to relocate to new habitats to avoid the effects of climate change. Adult giant snakehead fish completely lose this ability and are thus more vulnerable. The climate change vulnerability of *C. micropeltes* is relatively low at 1.9 (Figure 3). Given the quality of the species data, our overall confidence level for this assessment is very high.

4. CONCLUSION

Saltwater intrusion, droughts, high temperature, and permanent inundation can seriously threaten all future habitats and species. The proliferation of invasive alien species is also the main risk to the open water and Lung habitats. The Melaleuca and Lung habitats have a high baseline conservation status. The Melaleuca habitat is found to be more vulnerable than the Lung habitat. Open water and agricultural habitats are assessed as having low baseline conservation status, and open water habitats are identified as more vulnerable than agricultural habitats. The Melaleuca habitat is influenced by non-climatic factors such as encroachment for agricultural cultivation, the deterioration of water quality, and thick tree density. Most of the species selected for vulnerability assessment have a low baseline conservation level. The adaptability to climate change of *C. ornate* is much lower than that of the other species. *M. cajuputi* and *E. hygrophilus* have high adaptability under the impacts of climate change. Increasing salinity, doughts, and hydrological changes can moderately impact on the living environment of *C. micropeltes*

and *C. ornate*. The findings in this study could assist the managers in formulating water management plans to ensure the development and limit the risk of the habitats and species in Lung Ngoc Hoang NR.

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