Is it because of climate change? Social-ecological system analysis of wetland protected area in Vietnamese Mekong Delta

Loan Thi Phan
National Taiwan University
Chyi-Rong Chiou
National Taiwan University
Sue-Ching Jou (jouchen@ntu.edu.tw)
National Taiwan University
Ci-Jian Yang
National Taiwan University

Research Article

Keywords: Climate change, NDVI, social ecological system, wetland protected areas

Posted Date: June 21st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1743798/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Wetlands Ecology and Management on November 9th, 2023. See the published version at https://doi.org/10.1007/s11273-023-09960-1.

Abstract

Wetland protected areas (WPA) are among the most productive natural environments providing substantial socio-economic benefits to humans as well as habitat for numerous species. However, they are also highly vulnerable in the Anthropocene era due to various factors of population growth, unsustainable productions, climate change, etc. Assessing the land cover change of WPA and its driving force are necessary work for the sustainable development and management of WPA. Here, we investigated vegetation as an indicator for land cover changes in WPA because of its strong interaction with governance system and external related ecosystem of WPA, such as water resources, nutrient cycle, etc. Along with the change of vegetation, we examine how climate change contributes to WPA change and human management. With the complication of research tasks, social-ecological system (SES) approach was applied with three main elements: resource system (vegetation covers); external related ecosystems (climate change) and Governance system (wetland management) and their interactions through Ecological performance (Outcome). We contribute to the lack of temporary SES research in the coverage of External Related Ecosystems in the relation to Resource systems and Governance systems. The selected site is the first Ramsar site of Vietnam Mekong Delta - Tram Chim National Park (TCNP) which is located at the exit of the Mekong River flow into Vietnam's territory. The study used a mixed methodology with the Mann-Kendall rank test, Theil-Sen estimative method, and the Mann-Whitney-Pettit method to analyze trends of climate parameters in from 1978 to 2019. Besides, the wetland vegetation changes were detected by the analysis of Satellite images based on the Normalized Difference Vegetation Index (NDVI) from 2002 to 2020. We also used Public Participation Geographic Information Systems (PPGIS) and did desk review of local reports and previous research for local disaster timeline and governance system. The results show that climate in TCNP has a significant change with an increase in both temperature and rainfall in the dry season. However, a decrease of NDVI dynamics and an extension of lowland vegetation community are dominated trends of spatio-temporal change of vegetation. With SES approach, we indicated that climate change is not a main driver but is always perceived as an increased risk for biodiversity conservation of WPA. Consequently, maladaptive actions and regulations from governance system have been implemented, which can threaten to sustainable development of WPA. Therefore, this study contributes a more comprehensive viewpoint to conservation and adaptive management of WPA.

Introduction

Wetlands are amongst the most productive natural environments on the Earth providing substantial socio-economic benefits to humans as well as habitat for numerous species. Wetlands play a greater role in providing ecosystem services than other ecosystems (Costanza et al. 2014; Russi et al. 2013). In the water cycle, wetlands play a major role in receiving, storing, and releasing water, regulating flows, and supporting life. They also provide critical food supplies including rice and freshwater and coastal fish, freshwater, fiber, and fuel, and regulate the global climate by storage and sequestration of carbon, mitigating hazards (Joanna et al., 2020) as well as delivering the Sustainable Development Goals, etc (Ramsar Convention on Wetlands (RCW) 2018). Globally, wetlands cover over 12.1 million km2; however, wetlands are in long-term decline around the world; between 1970 and 2015, inland and marine/coastal wetlands both declined by approximately 35%, three times faster than the rate of forest loss (RCW 2018).

Changes in wetland vegetation and its driving factors are the most critical challenges scientists are facing because of the environmental complexity. Various factors impact changes of vegetation in wetlands including human factors like land use (Nguyen et al. 2017), water diversion through dams, dykes and canalization; Infrastructure development or environmental related factors like climate patterns, topography, hydrological regimes, rodents and pests, etc (Zhang et al. 2021). Currently, the effects of climate change are increasing, with a growing number of studies assessing the impact of climate on the change of wetland vegetation. Climate change can affect wetlands by direct and indirect effects of rising temperature (Yu and Gao 2020; Reddy and Delaune 2008), solar radiation, changes in rainfall intensity and frequency (Zhang et al. 2021). A warmer climate would accelerate the loss of water through evapotranspiration, which increases oxygenation of the exposed top layers due to water table drop (Lafleur et al. 2005). On the other hand, the areas with higher temperatures accompanied by more precipitation can promote photosynthesis, leading to primary production (Vitt et al. 2000; B¨ackstrand et al. 2010; Bu et al. 2011).

In tropical and lowland regions, precipitation contributes directly and indirectly to water for wetlands. An increase in precipitation particularly enhances the Normalized Difference Vegetation Index (NDVI) in arid areas because precipitation alleviates water stress and increases soil moisture. However, these effects become attenuated once they reach a certain threshold, after which there is no general linear relationship between precipitation and vegetation change (Zhang et al. 2021). Drought is the most deleterious climate phenomenon, which might considerably damage the wetland ecosystem, especially for peatlands. This may trigger a shift of plant communities to the more drought-tolerant vascular plants. Meanwhile, the flood has more positive impacts on vegetation development because of raised water levels and higher light-saturated photosynthesis (Salimi et al. 2021).

There are still various debates on how climate change contributes to wetland changes. Wetlands lie at the intersection of multiple nexuses including physical nexus such as the interface of land and water or different water bodies (Adler 2005), political nexus (i.e. multiple policies in wildlife, water quality, etc), land use nexus, etc (Downard et al. 2014). Therefore, issues of wetland are dynamic and shift according to annual hydrological changes, policies, land use, and population changes (Downard et al. 2014). Thus, wetlands are a complex but ideal social-ecological system (SES) to understand climate change adaptation. However, literature in the SES approach detected a lack of consideration of several SES components in the adaptation and vulnerability literature (Salgueiro-Otero & Ojea, 2020). This gap is larger for the interactions between social and ecological domains, and in the coverage of External Related Ecosystems (Partelow, 2018) with the climate pattern being a typical system. Therefore, in this study, we consider climate change impacts and adaptation to the changing landscape of wetlands as the main subject and investigate the interaction of ecological and social elements. This can facilitate decision-making and adaptive governance of wetlands in the context of uncertainty. The manifestations of climate change and its effects on each wetland area are different; so we argue that the climate model data has to be downscaled to the scale of the study area to obtain more reliable and realistic results. However, in many developing countries like Vietnam, climate change policies are state-centric in a top-down governance context. We argued that can lead to maladaptive solutions. Concluding, our study aims to contribute to the lack of research on the relationship between policies enacted to respond to climate change and the changing landscape based on that policy.

The first SES definition was made by the Russian microbiologist B. L. Cherkasskii in 1988 but developed thoroughly and widely known by Berkes and Folke (1998). Accordingly, "Social-ecological systems are complex, integrated systems in which humans are part of nature" (Berkes & Folke 1998). After that, Anderies et al. (2004) came up with a more comprehensive definition of SES than the one by Berkes and Folke (1998) and defined SES as an ecological system intricately linked with and affected by one or more social systems. Later, the SES definition developed by Anderies et al. (2004) inspired Elinor Ostrom to establish a refinement and restructuring of the SES framework (Ostrom, 2007; 2010) to more easily identify variables; improve conditions to compare cases; and develop a shared language, important for communication and wider understanding.

The evolution of the SES framework (SESF) is supported by a long history of empirical research on the commons, institutions, resilience, and collective action (e.g., Ostrom 1990, Agrawal 2001, Meinzen-Dick et al. 2002, Anderies et al. 2004, Wollenberg et al. 2007, Poteete et al. 2010, Folke 2006). Two SESF proposed by Berkes and Folke and Ostrom have some common grounds, including local contexts as drivers of change (Berkes and Folke, 1998) and social-economic – political settings and external ecosystems in SESF Ostrom (2009). However, Berkes emphasizes more on the link between social and ecological systems through knowledge and understanding of ecological dynamics. Therefore, Berkes's SESF-based studies are towards resilience, social learning, and transformation in adaptation (Folke, 2006). Meanwhile, the origins of Ostrom's SESF include seminal empirical work on common property theory, self-organization, and coupled SES interactions. Therefore, it serves as a template for diagnosing sustainability challenges and theorizing explanatory relationships on SES components, interactions, and outcomes within and across case studies. In this study, we combine both Berkes and Folke's SESF frameworks with an analysis of climate change as a driver for system changes and the interaction of ecological systems and social systems in response to climate change. We also analyze knowledge and understanding of actors and governance systems toward climate change and adaptation to understand its relation to the resilience of the resources system under the context of climate change. In addition, with the advantages of SESF of Ostrom (2009; 2010) in providing a list of variables that can be for analyzing the SES of a local, we selected variables that are suitable to the real contexts. Since SESF of both Berkes and Folke and Ostrom is context-dependent, therefore, the selected variables for both ecological systems and social systems are based on the real context (figure 1)

Within SESF (figure 1), subsystems such as a resource systems (RS), actors (A), and governance systems (GS) are relatively separable but interact to produce outcomes (O) at the SES level, which in turn feedback affects these subsystems and their components, as well other larger or smaller SESs (Ostrom 2009). In our case, ***Climate change*** is selected as an external driving force with its direct impact on wetland system changes mainly through temperature and rainfall factors. The changes in temperature and rainfall by seasons and years as well as extreme weathers such as flooding and droughts are one of the major factors causing local disasters such as forest fires. ***Water flows*** are external driving forces and are supplied by rainfall (climate factor) and river flows which are indirectly impacted by hydrological systems of upper streams and dam construction, therefore it is a more regional and transboundary scale factor. Therefore, water flows in this study are not considered as the main driving forces for vegetation change at a local scale but are instead still interwoven with climate change impacts in an analysis of the changes in water level in the wetland protected area (WPA), which impacts the vegetation and forest fires, and is managed by GS through construction such as sluice gates and canals. ***Vegetation cover*** is a main local resource system; therefore, detecting the spatiotemporal changes of vegetation are key in assessing the interaction of resource system changes and the external driving factor which is climate change, and the internal driving factors which are the governance system and the actors. ***Forest fire prevention*** is an integrated outcome of climate change impacts and governance system in water and vegetation management. Climate change can cause forest fires ((Nitschke & Innes, 2007), and when forest fires occur it impacts vegetation cover change (Dale et al., 2001; Overpeck and Rind,1990; Williams et al., 2010, IPCC, 2007), and GS deploys several adaptation actions to respond to forest fires; this is also a way to respond to climate change. ***Actors*** in our framework are mainly local residents who have lived on resource systems of WPA for their livelihood. This study will analyze how local residents perceive the impacts of climate change on the resource system by their participation in the co-creation of disaster maps and timelines of disasters to identify extreme events (such as drought, flood, forest fires, bank erosion) in both the spatial and temporal scales of national parks. This is also a necessary step in several climate change adaptation frameworks to determine problems, (Jopp et al., 2010 & 2015; Becken & Hay, 2007) but it does not appear in the SES framework. Furthermore, we also investigate how vegetation changes impact local livelihoods and how local residents respond to those changes. ***Governance systems*** with relevant stakeholders in this study are park managers and local governments at the commune, district, and provincial scales. Additionally, the governmental regulatory framework for natural resources, which is enacted from the state level and implemented by local governments, is also analyzed.

Thus, in this study, we have three steps: (1) Analyze the effects of climate change on temperature and precipitation; (2) Analyze the change of vegetation and predict the relationship of climate change with the change of vegetation (3) Analyze the relationship between wetland managers in response to the impacts of climate change on the vegetation through forest fires prevention management and public participation. Current studies applying SES are too focused on ecological systems and lack of considering social system elements (Huong et al, 2020); therefore, our study not only attempts to balance these two aspects but also filling the lack of studies applying SES in the analysis of an adaptation study (Salgueiro -Otero & Ojea, 2020).

Study Area And Method

Tram Chim National Park

Vegetation in the nexus with climate patterns

The study site is located in Mekong river delta (MRD) (figure 2), the largest delta in Vietnam and the world's third-largest delta with an area of about 60,000 km^2 and comprises a dense network of canals and dykes. Currently, Mekong river delta has been suffered serious vulnerability to environmental changes which result from unsustainable production of rice and shrimp productions, hydrological dam constructions in upper streams, and climate change impacts (Le et al. 2007). In which wetland areas are one of the typical landscapes and essential resources for environmental, social and economic development of MRD and are most sensitive areas under the impacts of environmental changes.

Tram Chim National Park established in 1998 was designated the 2000th Wetland of International Importance by the Ramsar Convention on Wetlands in 2012 and the first Ramsar site in the Vietnamese Mekong Delta (VMD). With an area of 7,313 ha, the landscape of the park comprises grasslands, open water, channels, and Melaleuca forest (figure 2). Wild Rice (Oryza rufipogon) communities are likely to survive to any extent and, therefore, one of the most important sites for the conservation of wild rice in Vietnam. This site is also famous for the population of Sarus Crane Grus (vulnerable species) and regularly supports more than 20,000 water birds in the dry season. Also, the wetlands of Tram Chim National Park are an important source of food, spawning grounds, nursery and migration paths on which fish stocks, within and outside the wetlands (Ni et al. 2006).

With a warm climate and abundant rainfall, the vegetation of TCNP grows green for the whole year. TCNP is an inland wetland area with fresh water, and marshes developed on inorganic soils, seasonal and herb-dominant, tree-dominated wetlands. There are six main biomes in TCNP including Melaleuca cajuputi (2435.7603 ha), Panicum repens (617.1078 ha), Eleocharis dulcis (820.8972 ha), Oryza rufipogon (Wild rice) (38.154 ha), Polygonum tomentosum (30.509 ha) and Nelumbium nelumbo (Lotus) (327.29 ha) (in 2016). Based on the inundated period of water which also influences the level of acid in the soil (Ni et al., 2006), we classified vegetation communities of TCNP into two types: upland and lowland communities (Figure 3). Upland community includes plants such as Panicum and Ischaemum which are located in drier and less acid areas with an inundated period less than 2 months. Meanwhile, lowland community includes plants such as Oryza rufipogh and Eleocharis Dulcis which are located in acid-sulphate soil layer and closer to the water surface with the inundated period from 4-6 months and floating species like Lotus can distribute in the area with 8-10 months inundated. Melaleuca cajuput can grow in a wetland when the depth of water is not high and the waterlogged duration is less than 6 months (Tran 2005; Ni and Tuan 2015).

Forest fire prevention is a critical and debatable issue in conservation at TCNP

Forest fire prevention is one of most concerning issues in TCNP. In only 5 years (2009-2013) there were 24 fires that destroyed a total of 294.13 ha grassland and 133.19 ha Melaleuca forest. Especially in A1 and A5 has 9 fires, one of the most severe fires happen in 2010 in zone A1 and zone A5 in 2009, others have from 1-3 fires (Ni and Tuan 2015). However, whether forest fire is a natural disaster and human-made disaster is still controversial. Meanwhile scientists supposed that all forest fires are human caused with illegal penetration of local peoples and accumulation of fuelwoods and grass (Ni and Tuan 2015). Provincial government concluded that climate change increases the risk of wildfires in this region (PCDTP, from 2010 to 2020). Besides, there is a disagreement in fire role between scientists and government. According to Ni and Tuan 2015, fire plays a role in melaleuca and Eleocharis Dulcis regeneration. Whereas, forest fire prevention was mentioned as a priority task in documents on conservation and sustainable development of Tram Chim National Park of the General Department of Forestry[1]. Since 2017, the NP started to reconsider about those regulations and have adjustment the Regulation No. 25/2017/QD-UBND of the People's Committee of Dong Thap Province (PCDTP 2017b) there are basic changes in forest fire and water management policies such as water management and regulation to adapt to conservation needs biodiversity and Ramsar Convention criteria; experimental study of controlled burning of grassland. However, there is still a lack of specific guidelines on implementation and therefore the change, as well as the impact in forest fire management in TCNP, is not significant.

Governance system in TCNP

Like 80% of national parks in Vietnam, TCNP is a national park under the management of the Provincial People's Committee (An et al. 2018). The implementation is top-down with the main management from the Provincial People's Committee and the consultancy of many related agencies, on approving and directing the implementation of management. The head of TCNP is a Board of managers including a director and deputy director who are responsible for general management and directly interact with provincial agencies and relevant departments. In the condition of a developing country with a limited budget for conservation, and people living standards in the buffer zone is low; therefore, TCNP also receives support from NGOs such as the International Union for Conservation of Nature (IUCN), World Wildlife Fund (WWF), World Bank (WB), etc in supporting people to diversify their livelihoods, as well as education to raise awareness of environmental protection.

The law used in the management and development of TCNP today is still based on the forestry law enacted in 2001 and revised in 2006, according to Decision No. 186/2006/QD-TTg dated August 14, 2006 of the Prime Minister of Vietnam. Accordingly, the national park is a special-use forest that needs to be strictly protected and all management is controlled from the provincial people committee under strict law system from Center government with fragmented overlapping participation and the division of responsibility between administrative levels is unclear (Dung et al. 2012, VNFOREST 2014).

As the first Ramsar site in the VMD, TCNP plays an important role in conserving biodiversity, especially native species such as Eleocharis Dulcis, Wild rice; Sarus Crane and other water birds. Climate change is identified as a culprit for disasters such as drought and increases the risk of wildfires in this region (PCDTP from 2010 to 2020[2]). Therefore, conservation in association with response and mitigation of climate change impacts on biodiversity and sustainable development is identified as an important task of TCNP.

Materials and method

Climate change and hydrological regime

We applied the Mann-Kendall rank test, Theil-Sen estimative method, and the Mann-Whitney-Pettit method to analyze trends of monthly temperature, rainfall in TCNP from 1978-2019 of Cao Lanh weather station (nearby TCNP). The surveyed climate factors include hourly temperature and daily precipitation which have major impacts on wetland vegetation (Reddy and Delaune, 2008; Salimi, et al 2021). Regarding temperature, we calculated the annual average temperature, minimum, maximum and average temperature by dry season (December to April) and rainy seasons (May to November). Regarding the precipitation, we investigated annual total amount, the amount of rainfall in maximum and minimum months (October and February, respectively); and in rainy and dry seasons. After that, we conducted trend analysis on an annual basis. For long-term trend analysis, we used the Mann-Kendall rank test to verify whether there is a significant trend change, Theil-Sen estimative method to evaluate the slope, the Mann-Whitney-Pettit method to find the change point (specific year when a significant change occurs) (Appendix I).

Landsat-based detection of vegetation changes and NDVI

Since wetlands are typically located in the transition zone between terrestrial and aquatic ecosystems with spatial heterogeneity and complex hydrological dynamics (Chen et al. 2020; Fuente et al. 2021), it is impossible to rely on single-phase remote sensing data to perform high precision monitoring and mapping of wetland ecosystems with low spatial resolution remote sensing data (Chen et al. 2018; Zhang et al. 2020a, 2020b). Besides, the heterogeneity of wetland landscapes has increased due to the influence of climate and human factors, and vegetation patches have become severely fragmented (Cai et al. 2020b; Mao et al. 2018). Therefore, remote sensing images with high spatial and temporal resolutions are urgently required for wetland vegetation monitoring. Landsat-based detection can be applied for regional scale mapping, usually capable of mapping vegetation at community level or some dominant species can be possibly discriminated. In this study, Landsat 7 and 8 with 30-m Level-1 products, collected from 2002 to 2020, were used to reveal the dynamic change in vegetation growth of wetlands on two national parks of Vietnam, which are located on the biggest estuarine delta on the Earth. The products were downloaded from USGS's Earth Explorer (EE) website and data portal (https://earthexplorer.usgs.gov/). Firstly, all Landsat data was mapped into the same projection UTM-WGS84 zone 48 N by Arc GIS 10.5 and therefore we may inspect the cloud cover and spatially distortion for reducing the error in the NDVI time-series for each pixel.

Among various spectral vegetation indices of wetland greenness, NDVI were most responsive to field-based metrics of vegetation structure and composition and most used in inland woody wetlands because of its most sensitive to plant structure, composition (Taddeo et al, 2019) and a relatively consistent NDVI threshold which can be used to differentiate wetland (White et al. 2016). NDVI is abbreviated from Normalized Difference Vegetation Index (NDVI) which is a measure of the state of plant health based on how the plant reflects light at certain frequencies (some waves are absorbed and others are reflected). NDVI derived from Landsat data was calculated by Matlab2021 based on this formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

NIR – reflection in the near-infrared spectrum

RED – reflection in the red range of the spectrum

In which, NDVI of Landsat 7 equal to (Band 4 − Band 3)/(Band 4 + Band 3); and NDVI of Landsat 8 equal to (Band 5 − Band 4)/(Band 5 + Band 4)) were derived from the product covering the rainy season and dry season since 2002. To reclassify surface cover into four types of NDVI, we used the function of Matlab2021 namely, Quantile. Method for calculating quantiles, we specially select the option of approximate to return approximate quantiles by implementing an algorithm that uses T-Digest (Dunning and Ertl 2017). Then, we validity the classified results by comparing the classification of ground mapping in 2016 and it demonstrates the acceptable level. After applying the method to other images for tracking the surface change, totally, we had calculated 10 images (table 1).

The density of vegetation (NDVI) at a certain point of the image is equal to the difference in the intensities of reflected light in the red and infrared range divided by the sum of these intensities. This index defines values from -1.0 to 1.0, basically representing greens, where negative values are mainly formed from clouds, water and snow, and values close to zero are primarily formed from rocks and bare soil. Very small values (0.1 or less) of the NDVI function correspond to empty areas of rocks, sand or snow. Moderate values (from 0.2 to 0.3) represent shrubs and meadows, while large values (from 0.6 to 0.8) indicate temperate and tropical forests.

Table 1. Characteristics of satellite images using for detecting NDVI changes by time of TCNP

	Dry season (from November to April)	Wet season (From May to November)
Sensor	Date of images	Date of images
Landsat 7	2002/March/17	2011/October
	2003/January/31	
	2008/March/09	
	2009/February/08	
Landsat 8	2014/ February/22	2014/September/22
	2015/ February/03	2018/October
	2020/ February/07	

The result of Matlab generates 4 thresholds which are different in each map. We based on the real data in which was collected in April 2016 (dry season) and the nearest time of Landsat images we collected (2014) to classify different vegetation categories from images. The results show that class 1 is matched with water bodies (like lake, canals, ponds). However, from class 2 to class 4, the vegetation mixed together and also different by seasons (table 5).

Disaster events in local and government adaptation actions

For the disasters, after a scoping trip to TCNP, we found the local government did not record local disasters within 20 years. Therefore, we used Public Participation Geographic Information Systems (PPGIS) to collect events of disasters occurring in local. With participation of 16 local residents and 5 officers who have been working in the national park management board and local government we created a disaster map and disaster time lime (Appendix II). PPGIS refers to methods for collecting spatial information from non-professionals (Brown and Fagerholm 2015). Brown 2017 remarked that the term “public” in PPGIS includes not only random public, but also decision-makers, implementers, affected individuals (i.e. stakeholders), or interested observers. PPGIS differs from empirical mapping methods (i.e. collecting secondary data or maps) in the direct inclusion of stakeholders (can be either experts or members of the public). There are two mapping technologies applying in PPGIS including digital mapping utilizing internet mapping services (e.g., Brown and Reed 2012; Brown and Brabyn 2012ab), and manual mapping relying on primitive markers such as stickers or beads on cartographical/topographical maps or aerial images (e.g. Fagerholm et al. 2012; Scolozzi et al. 2015; Palomo et al. 2014; Canedoli et al. 2017). In our research, we used the second way by using paper maps and markers which are more intuitive, hence considerably more appropriate to use in the less developed study areas (Fagerholm et al. 2012; Scolozzi et al. 2015). Besides, this way is cheap and efficient when working in rural WPA as TCNP.

To assess the human response to the effects of climate change and its impact on wetland changes, we conducted revising ecological management policies and regulations of government. Through secondary documents including local reports, policies as well as published articles we reviewed the changes in boundary, water level management, and disaster prevention and reduction policies implemented in different zones (spatial) and different time (temporal) from 2002 to 2020 in the research site.

Results

Climate change in Tram Chim National Park

The climate of TCNP exhibits a significant increase in temperature and this change has occurred markedly since 20 years ago. During 42 years from 1978 to 2019, regarding temperature, there is a significant increase in the average temperature of year and in January (p value <0.05) (table 2), meanwhile in April, the temperature increases but not significant (p value >0.05). The changing point is in 1999 for yearly temperature, in 2002 for April temperature and in 1999 for January temperature.

Table 2. Results calculated from Mann-Kendall method for temperature characteristics at Caolanh station (Dong Thap) from 1978-2019

	By year				April (the hottest month)				Jan (the coldest month)			
	S †	Z ‡	Yt §	P.T |	S †	Z ‡	Yt §	P.T |	S †	Z ‡	Yt §	P.T |
Tave	4.75	1.96E-06	0.021	23	1.38	0.16	0.009	24	9.32	1.16E-20	1	21
Tmax	3.69	0.0002	0.03	12	2.73	0.006	0.026	12	2.73	0.006	0.026	12
Tmin	-3.89	9.84E-05	-0.08	14	-2.02	0.04	-0.012	12	-2.81	0.0048	-0.072	14

†S - Mann-Kendall S - positive S value means an uptrend; a negative S value means a downtrend

‡ Z - standard normal deviate – p value

§ Yt - trend slope

| P.T – changing point

In the whole year, temperature increase (with S>0 in table 2) in all month with significant increase (p value <0.05) occurring in January, March, June, July, August, September, October, November and December.

Regarding rainfall, the rainfall slightly increases by year, in October, February and in dry season (S>0) but not significant (p value all >0.05). Only in rainy season, the rainfall has slight decrease trend (S<0) but not significant (p value = 0.9) (table 3).

Table 3. Results calculated from Mann-Kendall method for precipitation characteristics at Caolanh station from 1978-2019

	S	Z	Yt	P.T
Annual amount	0.44	0.65	1.50	17
Max month (Oct)	1.34	0.17	2.53	17
Min month (Feb)	1.09	0.27	0	19
Rainy season	-0.10	0.91	-0.44	36
Dry season	1.80	0.07	2.61	21

Thus, the change of climate is manifested in the increase of the mean annual temperature since 2001 and the annual temperature range since the early 1990s with the increase of maximum temperature and decline of minimum temperature. Meanwhile, the precipitation shows an insignificant increase. That leads to the risk of a large increase in evapotranspiration and potentially reduced surface water, increasing the risk of hydrological drought and forest fires for the region. The facts have shown that natural disasters also change over time according to the change of climate parameters. In the period after its establishment from 1998 to 2001, flooding was considered a risk for this area. However, after 2003 to present, droughts and forest fires in the dry season are considered to be major risks of the region (figure 4). In addition, drought years usually accompany with forest fire such as in 1998, 2010, 2016.

Interactions between external ecosystems and resource system of WPA

Positive response of vegetation to climate change

The interactions of vegetation cover and climate change are analyzed by NDVI dynamics by seasons and years. First of all, we find that there are many variations of vegetation corresponding to changes in rainfall between the dry and rainy seasons. The result of Landsat-based detection showed that NDVI has a difference between dry and rainy seasons. Specifically, during the rainy season, in all surveyed years, we found that in the wet season average NDVI (0. 152) is higher than that of the dry season (0.14). In the wet season, the landscape looks more diverse and vivid in all zones (figure 5). Specifically, Melaleuca is the vegetation that thrives in the rainy season, with the NDVI being mainly at medium and high, while in the dry season being mainly at low NDVI (table 4). Some marsh grasses like Is. Indicum, Ischeamum, Leersia sp - O. rufipogon, Panicum repens, Oryza rufipogon also thrive in the rainy season with medium and high NDVI value. Polygonum hvdropiper L in the dry season only concentrated in A1 zone, but in the rainy season, it developed in both A1 and A2 zones. Aquatic plants like Nelumbium nelumbo grow more widely in A1 in the rainy season. Figure 5 shows that the area with NDVI value < 0 shrinking in the rainy season, which results from the rapid growth of aquatic plants (floating and emergent plants) on open water bodies. Whereas, in dry season, low NDVI dominates all zones of TCNP. The seasonal change of vegetation reflects the essential role of rainfall in the development and transformation of seasonal vegetation. In the wet season with major proportion of rainfall which provide abundant water for vegetation grow lush and healthy and even cover water surface of canals, ponds, etc.

Table 4. Spatial distribution and NDVI classification of vegetation cover at TCNP

NDVI classification	Tram Chim National Park			
	Dry season (Feb/2014)		Wet season (Sept/2014)	
Class 1 (<0)	Open water bodies (ponds) and water canals without aquatic plants			
Class 2 (Low_NDVI vegetation) (0 to 0.2)	Name of vegetation	Zone	Name of vegetation	Zone
	Melaleuca forest	A1, A2, A3, A5	Eleocharis dulcis	A1, A3, A4, A5
	Oryza rufipogon	A1, A2	E. atropurpurea	A1, A5
	Leersia sp - O. rufipogon	A1	Xyris indica L	A4, A5
	Panicum repens	A1, A2, A3, A4, A5	Oryza rufipogon	A1
	E. atropurpurea	A1, A5	Panicum repens	A1
	Eleocharis dulcis	A1, A2, A3, A4, A5		
	Is. Indicum	A4		
	Ischeamum	A1		
	Xyris indica L	A4, A5		
Class 3 (Medium_NDVI vegetation) (0.2 to 0.4)	Melaleuca forest	A1, A4, A5	Melaleuca forest	A1, A2, A3, A4, A5
	Eleocharis dulcis	A1	Oryza rufipogon	A1, A5
	Polygonum hvdropiper L	A1	Eleocharis dulcis	A1, A5
	Nelumbium nelumbo	A1	Panicum repens	A1, A2, A3, A5
			Is. Indicum	A4
			Ischeamum	A1
			Polygonum hvdropiper L	A1, A2
			Nelumbium nelumbo	A1
Class 4 (High_NDVI vegetation) (>0.4)	Polygonum hvdropiper L	A1	Melaleuca	A1, A2, A5

			Nelumbium nelumbo	A1
	Nelumbium nelumbo	A1	Oryza rufipogon	A1
			Leersia sp - O. rufipogon	A1
			Eleocharis dulcis	A1
			Panicum repens	A1, A3
			Polygonum hvdropiper L	A1, A2

Secondly, over years, recovery of vegetation was found mainly in rainy season with an increase of medium_NDVI vegetation areas (figure 6). In addition, a transformation from low_NDVI to medium_NDVI vegetations was found scatteredly in some marginal areas of the Melaleuca forest and from low_NDVI and medium_NDVI to high_NDVI vegetation in the boundary of zone A1 and A5; and A2 and A4. Most of open water spaces in zone A5 and southwest of Zone A4 was transformed to medium_NDVI vegetation (dark blue) and low_NDVI vegetation (light purple) (figure 6b). This is also a sign of the recovery of Xyris indica L and Eleocharis Dulcis in these areas. Water body was shrunk significantly in 2014. However, water gradually increased in 2018 especially in the west of zone A1 which is also area of aquatic plants like Nelumbium nelumbo and Polygonum hvdropiper L.

The transformation of the dominant vegetation communities of TCNP also changes over time, from 2009 to 2016, the statistical results show that, in 2009 and 2013 (Ni & Tuan, 2015), the six dominant biomes were Melaleuca, Panicum, Eleocharis, Ischeamum, Nelumbium nelumbo, O. rufipogon. Whereas, in 2016, Ischeamum vegetation had gradually shrunk and was replaced by Polygonum tomentosum occupying with a significant area (30,509) (table 5). The biological succession of this area dominates with a transition from upland community like grass to lowland community like emergent and aquatic plants. It can be speculated to be due to the increase of the water level of the TCNP especially in the dry season in recent years.

Table 5. Area changes of the major plant community at TCNP in 2009, 2013 and 2016

		Area of plant communities by years			Trend of change from 2009 to 2016
No.	Plant communities	2009	2013	2016	(+ increase; - decrease)
1	Melaleuca	1901	2211	2435.7603	+534.7603
2	Panicum	451	269	617.1078	+166.1078
3	Eleocharis	1109	651	820.8972	-288.1028
4	Ischeamum	26	6	Polygonum tomentosum (30.509 ha)	
5	Nelumbium nelumbo	221	85	327.29	+106.29
6	O. rufipogon	27	37	38.154	+11.154
7	Mix-up	3853	4329	3073.8	-779.2

Thirdly, the increase of temperature in the whole year especially in dry season can be a culprit of extreme events like droughts, forest fires in recent years. Based on the disaster map which is made by local community and park's officers (figure 7), the zone A1 suffered most natural disaster events such as floods in 1996, 2000, 2004, 2011; forest fires in 1996, 2006, 2010, 2014, 2016 as well as droughts in 2008, 2010, 2016. This partly explains the drastic change of NDVI dynamics especially in grassland areas such as Eleocharis dulcis and Ischaemum which have significantly decreased.

Negative response of vegetation to climate change

Although the water amount in dry season from rainfall has significant increase, degradation trend still dominates in vegetation cover in dry season especially after 2008. The change is more obvious with a decrease of medium_NDVI vegetation including part of Melaleuca forest; Eleocharis dulcis; mainly distributing in the A1 zone. Instead, after 2014, there is an increase of low_NDVI vegetation in all zones A2, A3, A4, A5, the low_NDVI vegetation increase in the area with diverse vegetation like Melaleuca forest; Oryza rufipogon; Leersia sp - O. rufipogon; Panicum; E. Atropurpurea; Eleocharis dulcis; Is. Indicum; Ischeamum; Xyris indica L (figure 6). In the whole period from 2002 to 2020, a large area of medium_NDVI vegetation has transformed to low_NDVI vegetation (light green color) is dominated in all zones (figure 6a).

In brief, through the large-scale decline of NDVI in TCNP, we argue that climate change has manifested a small impact on a few areas by increasing the risk of forest fires which has been recorded to occur on a small scale in TCNP. Other causes that have a greater impact on the large-scale decline of vegetation in the TCNP may stem from human management and other external ecosystems such as water level, the amount of sediment, etc.

Regarding factors influencing to landscape changes of VMR, beside on climate change, hydrological regime changes of the Mekong river as well as intensive rice production are mentioned as main factors (ICEM 2010; Nguyen et al. 2017; Le et al. 2015). The hydrological regime of the Mekong River in general and its two tributaries in Southern Vietnam, Tien and Hau rivers, have two distinct dry seasons and flood seasons. The dry season usually lasts from December to May of the following year, and the flood season is usually from June to November. However, in the past two decades, the change of water resources from the Mekong River into the

Vietnamese Mekong Delta is unstable and unpredictable in each part of Mekong River Basin. Research of Lu and Chua 2021 stated the water flows from upstream Mekong river to Vietnamese Mekong Delta reduced significantly after 2010 since hydropower dams have significant impacts on increasing droughts not only in dry season but also droughts in wet season. The 2019-2020 drought is thus both a natural hazard compounded with manmade vulnerabilities. However, our data during the period 2001-2016 shows that the water flow from the Mekong River through Tan Chau station which is located at the exit of water flows from Mekong river to Southern Vietnam tended to increase significantly in the dry season (from December to May (next year)) with $p<0.05$, while the flood water level from 1978- 2020 tends to decrease with $p<0.05$ (table 6).

Table 6. Results calculated from Mann-Kendall method for water flow characteristics at Tan Chau station (An Giang)

	S	Z	Yt	P.T
Q_value in dry season (from 2001-2016)	4.11	4.008352e-05	131.95	1 (2002)
Flood water level (from 1978-2020)	4.11	4.008352e-05	-0.87	1 (1979)

The increasing trend in water discharge at Tan Chau station is similar to the change in the rainfall regime in dry season. In previous studies, that trend can have a positive impact on vegetation especially in the context of prolonged drought and water shortage is serious (Salimi et al. 2021). However, our above analysis has shown that NDVI of TCNP has even declined by years. Therefore, we argued that the decline of NDVI and the transition from upland community to lowland community may be the result of human factors.

Relationships between resource system, external ecosystem and governance system

Human intervention in the natural system surrounding the TCNP has long history since after 1960-1970s a large network of canals was excavated across the Plain of Reeds to lower wetland water tables and also impacted to average flooding in the depressions decreased from 12 months to 4-6 months (Hanhart and Ni. 1993). From 1990-1996, under pressure of population increase and rice production, a large reclamation on the Plain of Reeds required digging canals and drainage to remove acidity from soils. However, it caused several environmental issues like soil acidification and loss of functioning wetland ecosystem (Ni et al. 2006; Ni and Tuan. 2015, Ni 2003). In 1994, Tram Chim Wetland Protected Area was established and then was upgraded to Tram Chim National Park in 1998 with initial purpose to protect Sarus Crane. Since then to now, there are several regulations and operations implemented, which modified TCNP environment (table 7).

Table 7. Timeline of remarked regulations/actions implemented and its impact zones in TCNP from 1994-present

Time	Actions/regulations implemented	Purpose	Impacted zones
1994-1996	Infrastructure development	Create the boundary for the national park	A1, A3, A2
	Water level regulation (through gates and boundary canals)	Regulate water level Forest fire control	
	Buffer zone socio-economic development and research	Reduce penetration of people into core zones	Buffer zone
1995–2004	Keeping high water levels inside Tram Chim	Prevent forest fires	A1, A2, A3, A4, A5
2000	Complete 60 km of dike around TCNP	Store water Forest fire control Recover Eleocharis Dulcis to attract Sarus crane	A1, A2, A3, A4, A5
2001	Prescribed fire in some grass areas to decrease the risk of uncontrolled fire by reducing fuel loading		
	Water level has been regulated according to plan: dikes, water gates, protection stations, digging ponds, boundary poles, fire controls		
2005-2008	A comprehensive fire and water management plan was developed and tested at Tram Chim by a team of international experts		A1, A2, A3, A4, A5
2008	A sharing benefits of fuelwoods towards wetland resource management has been applied in Tram Chim	Reduce illegal penetration of people into core zones Local people can harvest grass and wooden fuel at some time to reduce accumulated fire fuels	A1, A2, A3, A4, A5
2011 to present	The plan was approved by Vietnamese authorities to be applied permanently at Tram Chim		Buffer zone and core zones

(Source: Referred from Meynell et al. 2012; Torell et al. 2003)

The relationship of the related ecosystems (climate change) and resource systems (vegetation) and governance system (top-down law system and practical implementation) is clearly expressed through the process of achieving Ecological performance (a part of Outcome in SES) (figure 1). In the case of TCNP, the Ecological performance is most evident in the three management goals of TCNP: preventing forest fires, increasing the area of the native species Eleocharis Dulcis, and restoring the ecosystem to attract the iconic bird of TCNP (Sarus crane) (Ramsar Information Sheet (RIS), TCNP, 2012). Based on the synthesis of disaster prevention reports of Dong Thap province from 2010 to 2020 (PCDTP from 2010 to 2020) climate change is perceived as a risk which often used to explain for failures in water management of TCNP especially after 2014, but the decrease of water flow from the Mekong river is perceived as the main drivers for the shortage of water in NP in the dry season and also for strategy of water retention. This makes water and forest fire management is identified as the key adaptation activity of governance systems (table 7). Specifically, the disaster map showed that among all extreme events were mentioned by local people and officers, the historical flood in 2000 was mostly mentioned. That can be a focusing event (Birkland 1998) for boosting the implementation of a dyke system around TCNP after 2000, which also plays a key in vegetation transformation of TCNP. A dike system surrounding national parks with a length of up to 60km was constructed in 2000 to regulate water through a system of sluices and spillways located at the surrounding dike (table 7). Since 2000 to present, to reduce the risk of fire in the dry season, the water level inside the national park is always kept higher than the conditions in the past. In addition, to store water for firefighting, old ponds inside the park were dug and extended (table 7). Thus, almost all areas are affected by human factors through water level adjustments, especially zone A1, A2, A3. That adjustment has narrowed the water tables in flood season and dry season (figure 11) and zones of A1, A2, A3 have become too wet for many vegetation species compared to the optimum conditions (Ni et al. 2006). That explains the transformation of upland communities to lowland communities in these zones (figure 8).

However, the decline of NDVI in all zones (figure 6) and native species in TCNP present a decrease in the health of the TCNP ecosystem and a failure of TCNP in ecological performance. Ecological succession with the expansion of lowland vegetation in contrast to the changing climate patterns reveals a significant intervention of human actors into natural laws. A tendency to cope rather than adapt the climate change and a human-based solution instead of a nature-based solution can be noticed in WPA management of the Vietnamese Mekong Delta.

Discussion And Conclusion

From social ecological system framework (Ostrom 2009) in our context (figure 2) we found that in a WPA, climate change is an external related system, but in most government documents and policies, it is blamed as a main culprit for drought, floods, and forest fires in many local reports. Climate change is real, however, blaming on CC and inflexible top-down management presenting in government system and dominating in environmental management in general and climate change in particular in many developing countries (Painter et al. 2020) lead to maladaptive actions. There are many previous studies that have demonstrated that the impact of climate change has both positive and negative effects on the vegetation of wetland (Zhang et al. 2021; Reddy and Delaune 2008; Lafleur et al. 2005; Vitt et al. 2000; B¨ackstrand et al. 2010; Bu et al. 2011). However, our research shows the fact that climate change has an effect, but its impacts are not dominant and significant on the change of vegetation compared to human factors, especially in government management. Firstly, the impact of climate change is not significant on vegetation, an increase in temperature can cause forest fires, but rainfall in the dry season tends to increase, which can reduce this risk. Therefore, although the amount of water in this area is predicted to decrease, the vegetation of the lowland community has increased. Droughts tend to increase, but natural wildfires are decreasing, while forest fires caused by man-made ones have increased. Thus, the study once again confirms the importance of governance system in common resource management at local scale as (Ostrom 2009:421) emphasized that “If the initial set of rules established by the users, or by a government, are not congruent with local resource conditions, long-term sustainability may not be achieved”.

Another contribution of the study is to provide a new lens of ecological performance in social ecological system. Our study analyzed forest fire prevention as ecological performance of human and nature interaction in WPA. Forest fires are identified by governments as a risk from climate change and therefore fire prevention is an important conservation goal. Positively speaking, wildfires are recorded to be decreasing, and although the number of forest fires after 2001 tends to increase in number, the intensity is small and the majority is prescribed burning with rangers control. However, the intervention of coping solutions such as the construction of dykes, sluice gates, and high water storage to fight forest fire has caused many negative impacts on the landscape. With a high water retention policy, especially in the dry season, many plants in the upland community have been degraded, such as the decline of Eleocharis Dulcis, Ischeamum which are native plant species and a source of food for many precious bird species such as Sarus crane. Our study raises a critical question of who and how to define ecological performance in SES? We suppose the management mechanism based on “visible” outcomes such as forest fires reduction without having insights into other tacit factors such as composition, quality, changing trends of vegetation will lead to maladaptive actions. Perception of ecological performance therefore requires flexibility and locality. Although the top-down management mechanism dominating in Vietnam and policy change requires time and rigid, TCNP is an interesting case because it reflects a timely response with the adjustment of regulations over time with supports of NGOs and scientists’ community. Therefore, in the coming time, overcoming mistakes from water management as well as restoring degraded ecosystems in the context of climate change, unsustainable development and hydrological changes of the Mekong River would be a critical issue and need an engagement of scientists and the openness of the governance system.

Based on those analyses, we propose a new management strategy for WPA with more focus on a nature-based and context-based solution. Accordingly, we suppose that climate change and water flow change are a new context of WPA, therefore setting up the ecological performance (Outcome) in WPA needs to base on the real context and related systems as well as bottom-up management with local community engagement instead of top-down regulations which are rigid and broadly implemented. The limitation of the study is that it has not been clearly shown the contribution proportion of other factors such as the influence of hydrological dams on the upper stream of Mekong River, land use and others like pest and rotten leading to biodiversity degradation. That can be fulfilled by future research in this area.

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Figures

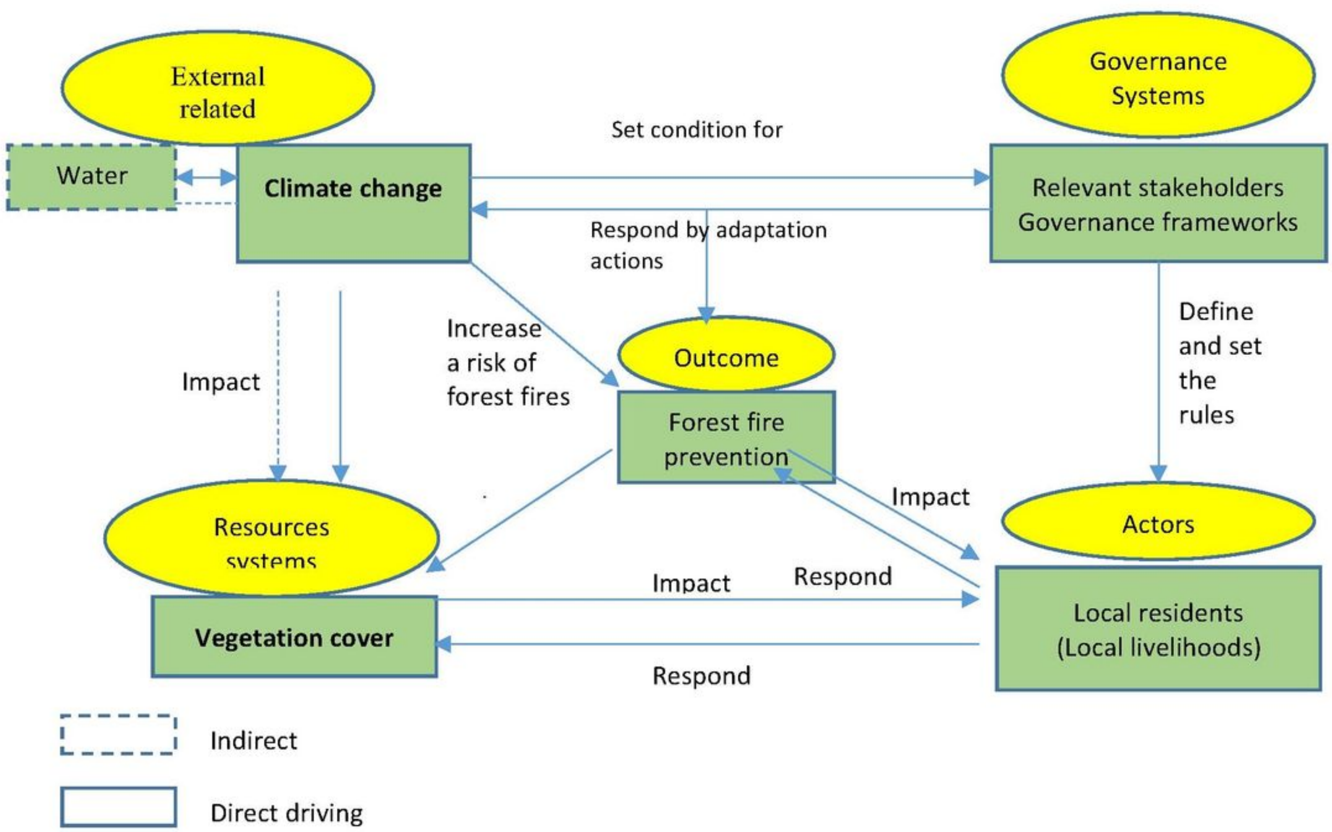


Figure 1

An analytical framework the interactions of 5 dimensions of SES including RS, GS, ECO, A and Outcomes in the case study. (Note: *Yellow circles are variables of SESF; Green boxes are context based elements in the case study which can be modified based on the real context***)**

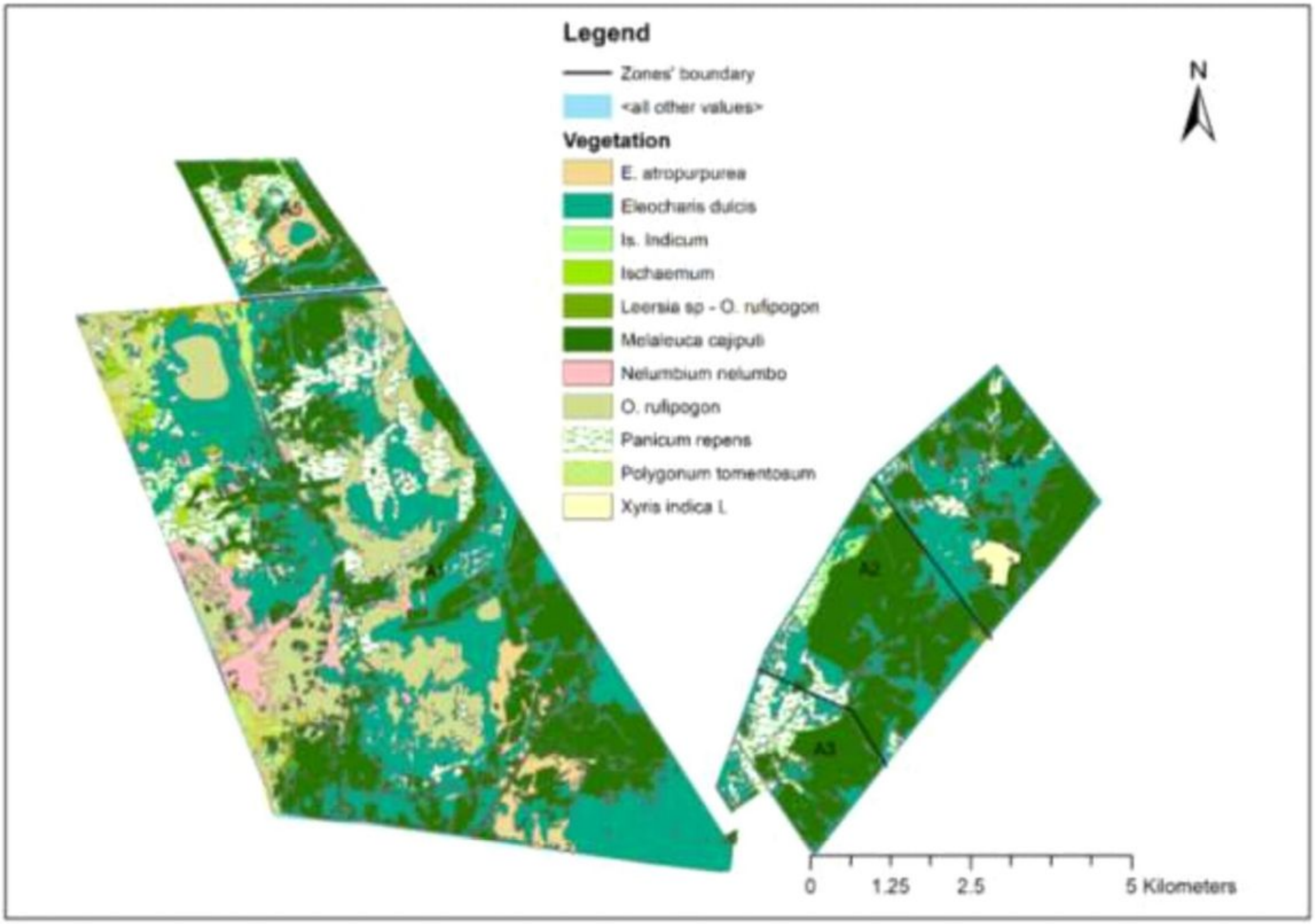


Figure 2

Location and vegetation cover map of Tram Chim National Park (TCNP)

(*Note: Currently, the core zone of TCNP is divided into five separate management zones: A1, A2, A3, A4, A5. Each surrounded by canals with a total of 60 km in length. Each zone has different functions and strict management level. Zone A1: 4,939.8 hectares, strictly control, and exploited for ecotourism for the whole year. Zone A2: 1,120.8 hectares prioritizes fisheries management; open for tourism activities in flooding season under the strict control. Zone A3: 41.8 hectares, strictly control, no outsiders penetrate. Zone A4: 730.5 hectares, strictly control, no outsiders penetrate, prioritizes Eleocharis Dulcis recovery. Zone A5: 434.1 hectares, prioritizes Eleocharis Dulcis recovery and Xyris indica L conservation for tourism activities.) **(*Source: Tram Chim National Park database April 2016*)**

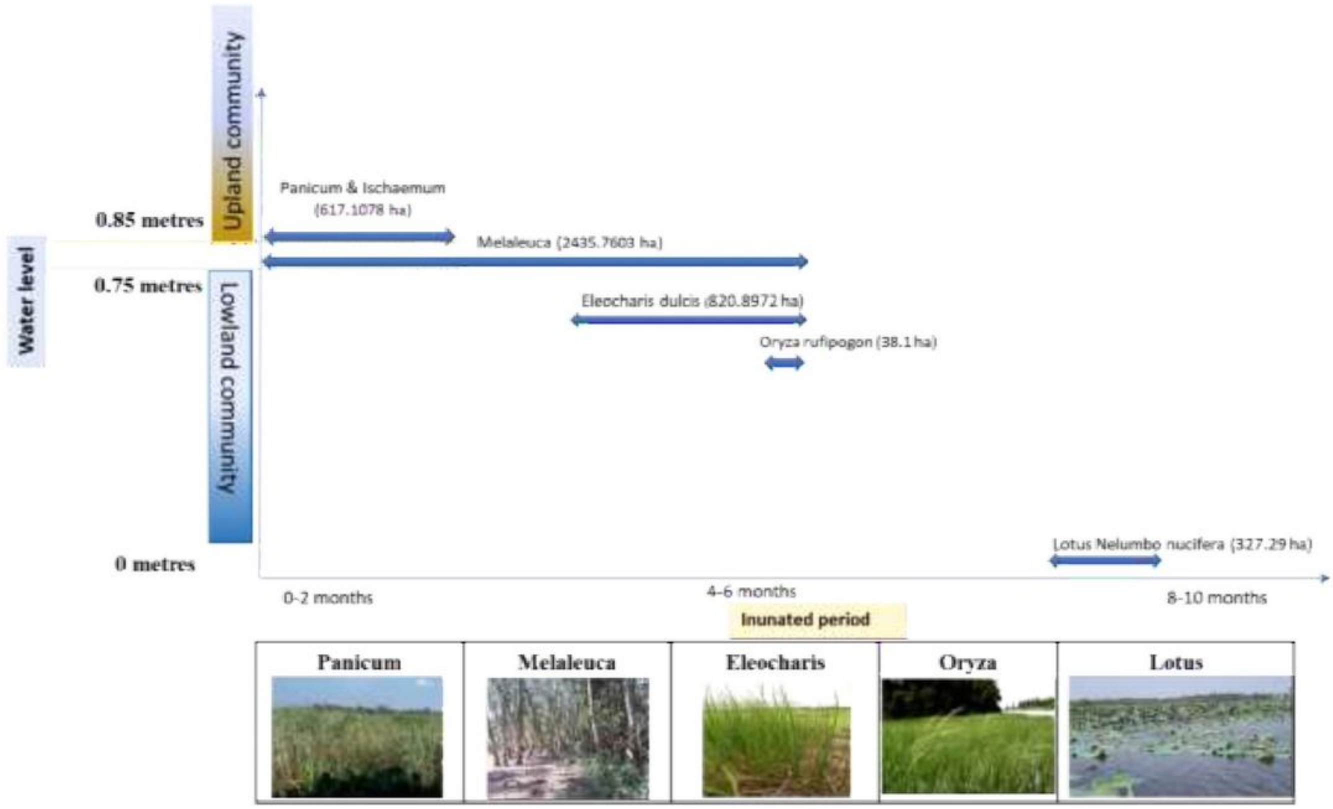


Figure 3

The distribution of dominant vegetations of TCNP along with water inundation and acid level of the soil.

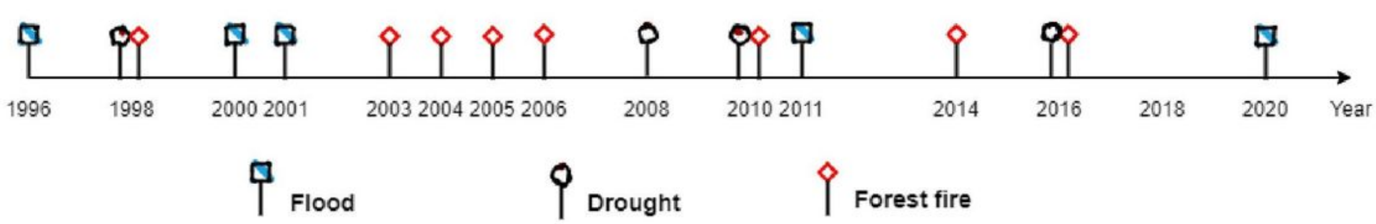


Figure 4

Timeline of disasters in TCNP (made by community and managers of TCNP)

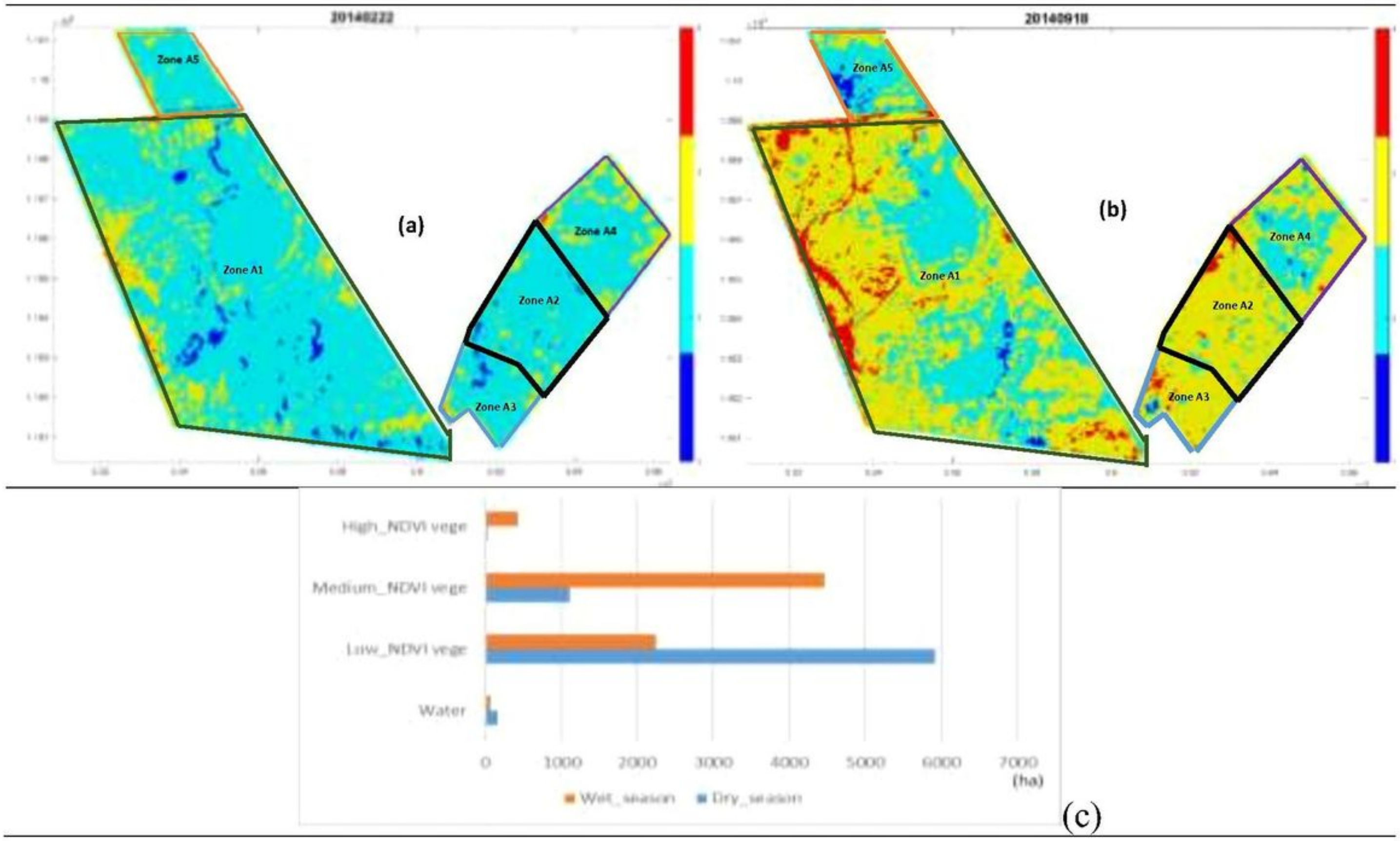
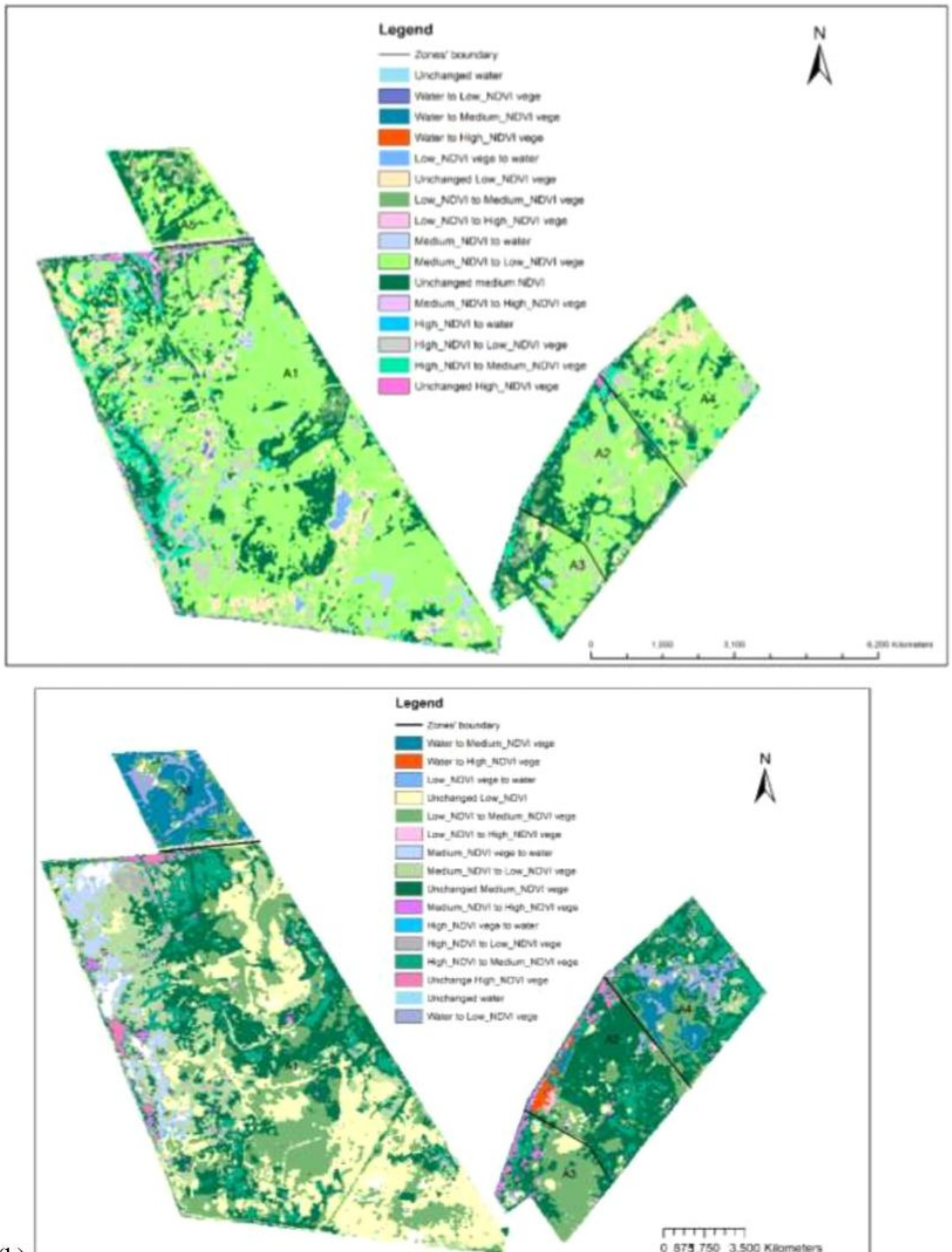


Figure 5

The difference of vegetation and water cover in 2014 of TCNP in dry season (a) and rainy season (b) and the change of NDVI by season in 2014 (c)

(a)



(b)

Figure 6

Transition map of landscape from 2002 to 2020 in dry season (a) and from 2011 to 2018 in rainy season (b)

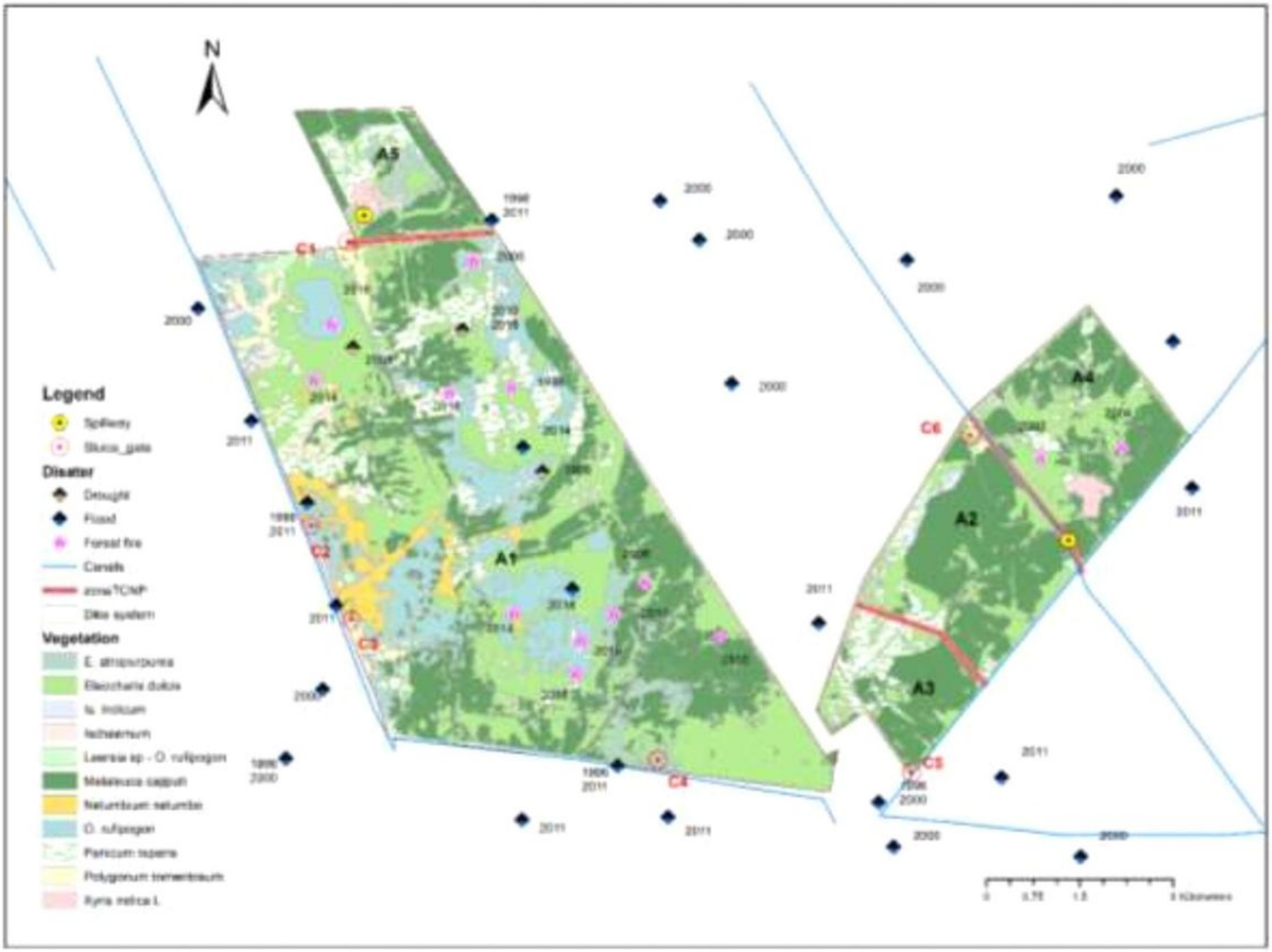


Figure 7

Disaster map of TCNP from 1996-2020 (made by local community and officers)

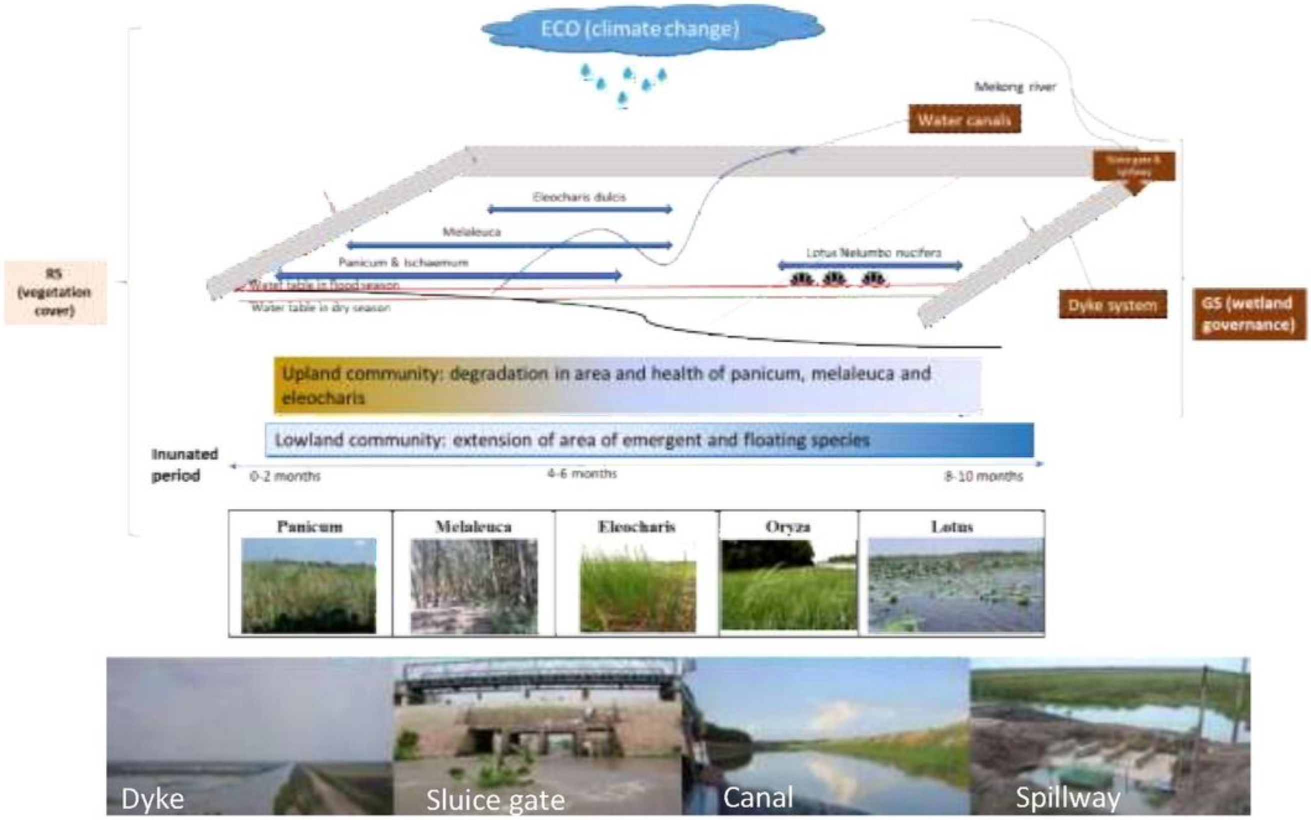


Figure 8

The relation of ECO – RS – GS in a schematic of wetland vegetation communities associated with changing hydrological regime under human intervention

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementary.rar