**An Indicator Framework for Assessing Socio-Ecological Resilience of Candaba Wetlands, Philippines**


**Abstract**

Candaba Wetlands, a priority wetland and vital production landscape in the Philippines, exemplifies the intricate interplay between agriculture and ecology, providing a wealth of ecosystem services and enhancing the well-being of local residents.

This paper introduces an indicator framework for assessing the socio-ecological resilience of Candaba Wetlands, drawing upon a comprehensive review of resilience literature and the principles of Socio-Ecological Production Landscapes and Seascapes (SEPLS).The SEPLS resilience model underscores the interconnectedness of ecological and social systems, providing a robust foundation for the proposed indicator framework. The framework is organized around four key areas of SEPLS resilience: (a) ecosystem protection and biodiversity maintenance; (b) agricultural biodiversity; (c) knowledge, learning, and innovation; and (d) social equity and infrastructure.

Within each area, indicators are further delineated according to the ecosystem, agricultural, and social dimensions specific to Candaba Wetlands. This nuanced approach allows for a comprehensive assessment of the wetland's resilience, capturing the complexity of its socio-ecological dynamics. Moreover, the framework serves as a valuable tool for engaging stakeholders in efforts to sustain and enhance the resilience of Candaba Wetlands, facilitating effective communication and collaborative decision-making.



*Keywords: wetland, resilience assessment, socio-ecological dynamics, landscape approach, urban planning*

## 1. Introduction

The concept of resilience has become a focal point for many researchers studying the disturbance and change of socio-ecological systems (SES) (Callo-Concha & Ewert, 2014; Ifejika Speranza et al., 2014a; Quandt, 2018). SES are complex networks shaped by the intricate interactions between social systems and ecosystems (Chaffin & Scown, 2018; Cumming & Peterson, 2017; Dennis, 2015; Ives et al., 2007; Knapp et al., 2010; Peterson et al., 2003). These interactions have profound effects on biodiversity and ecological processes within SES (Jeynes-Smith et al., 2023). Moreover, temporal changes in SES can significantly impact the ecosystem services of wetlands (Liu et al., 2007)

From a socio-ecological system perspective, the resilience characteristic of a system allows it to absorb disturbances and reorganize while undergoing change, thereby retaining its function, structure, identity, and (Adger, 2006; Folke, 2006; Gunderson & Holling, 2002; Holling, 1973; Panpakdee & Limnirankul, 2018; Smit & Wandel, 2006; Urruty et al., 2016; Walker et al., 2006). However, due to the complexity and dynamics of interrelations in SES, measuring its resilience poses a significant challenge (Lade et al., n.d.; Tamberg et al., 2020).

To address this, the Japan Satoyama-Satoumi Association (2010) integrated resilience thinking into socio-ecological production landscapes and seascapes (SEPLS). SEPLS refers to the mosaic production landscapes formed by human-nature interaction that sustain human well-being while maintaining ecosystem services. It links the biological, physical, and social components, which are manifested in traditional knowledge and the sustainable use of biodiversity (Boafo et al., 2016; Boafo & Ichikawa, 2016; Fiksel, 2007; Folke et al., 2010; Takeuchi et al., 2016)

In the Philippines, the Candaba Wetlands is an example of socio-ecological production landscape that has been primarily an agricultural area, a fishing ground and a wetland ecosystem at the same time. This wetland have been exposed to various recurrent disturbances such as agricultural activities and flooding. Despite these disturbances, this wetland remains a key biodiversity area in the Philippines and is globally important in the East Asian Australasian Flyway of waterfowls. The residents have adapted to the changing landscape through shifting livelihoods, demonstrating the resilience of the wetland (Meyer, n.d.).

The question then arises, "What makes Candaba Wetlands resilient?" Considering the concepts of resilience and SEPLS, this study aims to identify indicators suitable to the context of Candaba Wetlands that could be used in measuring or assessing its socio-ecological resilience. To achieve this, a systematic literature review was conducted to analyze various resilience frameworks and assess their applicability to the Candaba Wetlands. The findings from this review will provide valuable insights into the strengths and weaknesses of various resilience frameworks and their applicability to socio-ecological landscapes like the Candaba Wetlands.

## 2. Defining Resilience

Resilience, as a concept, has been a subject of extensive debate and exploration in ecological studies. Holling (1973) introduced and defined resilience as a measure of a system's persistence and its ability to absorb changes in state variables, driving variables, and parameters while maintaining the same relationships with these variables. He contrasted resilience with stability, defining the latter as the system's ability to return to an equilibrium state after a temporary disturbance, resulting in the degree of fluctuation.

The resilience and stability perspectives on system behavior have distinct implications for resource management. While resilience emphasizes the "domains of attraction and the need for persistence," stability focuses on maintaining equilibrium and harvesting nature's excess production with minimal fluctuation (Iglesias & Whitlock, 2020). Some scholars view resilience as the time required for a system to return to an equilibrium or steady state following a perturbation. In this perspective, resilience is measured by how far the system has deviated from equilibrium and the speed at which it returns to its steady state (Schlüter & Herrfahrdt-Pähle, 2011).

Gunderson (2000) posited that resilience is an emergent property of ecosystems, linked to self-organized behavior over time. He associated self-organization with the interaction between structure and process, leading to system development. This perspective aligns with Holling’s adaptive cycle's exploitation phase, where a system can absorb a range of disturbances, indicating high ecological resilience. However, when a system reaches its conservative growth limits, it becomes primed for rapid structural changes.

Walker et al. (2004) offered a comprehensive definition of resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change to retain substantially the same function, structure, identity, and feedbacks." This definition underscores that an ecosystem's ability to reorganize and renew itself after perturbation depends on states and dynamics at various scales. Resilience is dynamic, changing over time, with human actions potentially eroding resilience. Disturbances that were previously absorbed can lead to a regime shift. Thus, resilience encompasses both recovery and change elements, emphasizing adaptive capacity while considering the sensitivity of human and ecological systems (Ibarraran et al., 2008).

Mumby et al. (2014) distinguished between two forms of resilience discussed in literature: ecological and engineering resilience. Ecological resilience considers ecosystems that can evolve towards one or more community types, even without acute disturbance events. While it is ideal for ecosystems at risk of losing their recovery ability and moving to an undesirable state, it can be challenging to quantify (Lu, 2010) In contrast, engineering resilience applies to systems that consistently recover towards the same long-term state. It is beneficial where ecosystem recovery is common but falls short in systems with frequent disturbances since it focuses on an equilibrium state (Schlee et al., 2012).

## 3. Comparing Resilience Frameworks

Resilience is a critical attribute across a multitude of domains, from social systems to infrastructure and power systems. This following are synthesis of the key findings from comparing several resilience assessment frameworks, including the Socio-Ecological Production Landscapes and Seascapes (SEPLS) model, the Resilience Alliance's Resilience Framework, and the Stockholm Resilience Centre's Framework, among others (Almutairi et al., 2020; Torralba et al., 2023; Yang et al., 2020)

### 3.1. Holistic Approach and Stakeholder Participation

The SEPLS model is renowned for its holistic approach, emphasizing the harmonious coexistence of people and their natural environment. It integrates various types of knowledge, including traditional, scientific, and local, and underscores stakeholder participation and forward-looking strategies (Torralba et al., 2023)). This holistic approach ensures that all aspects of a socio-ecological system are considered, and that local communities are actively involved in decision-making processes. In contrast, the Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework, while also considering socio-ecological systems, do not explicitly emphasize the integration of various types of knowledge or stakeholder participation. They tend to focus more on the dynamics of socio-ecological systems and the capacity of a system to absorb disturbance and reorganize, without giving equal weight to the role of local communities and stakeholders in resilience building (Cundhill et al., 2010; Stockholm Resilience Centre, n.d.)

### 3.2. Consistency in Key Concepts

Saja et al. (2019) identified inconsistencies in the key concepts used to measure social resilience in disaster management frameworks, leading to confusion in interpretation and application. They advocated for a comprehensive social resilience framework adaptable to different contexts and integrated with specific measurement tools and guidelines (Saja et al., 2019). In contrast, the SEPLS model, the Resilience Alliance's Resilience Framework, and the Stockholm Resilience Centre's Framework provide more consistent key concepts, each having a clear focus on their respective domains. The SEPLS model, for instance, provides a clear framework for understanding and assessing the resilience of socio-ecological production landscapes and seascapes, with well-defined concepts and indicators (Torralba et al., 2023; Yang et al., 2020). The Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework, while also providing consistent key concepts, do not offer the same level of clarity and adaptability as the SEPLS (Cundhill et al., 2010; Stockholm Resilience Centre, n.d.).

### 3.3. Focus on Governance, Institutions, Infrastructure, and Society

Almutairi et al. (2020) found that coastal community resilience frameworks for disaster risk management focus mostly on governance, institutions, infrastructure, and society and economy, with less emphasis on the environment and potential risks of climate change. They identified 64 critical resilience criteria under four dimensions, emphasizing the importance of governance and institutional arrangements in building community resilience (Almutairi et al., 2020). The SEPLS model, however, provides a more balanced consideration of various factors, including governance, institutions, infrastructure, society, economy, and the environment. It emphasizes the need for good governance and institutional arrangements that respect local traditions and cultures, promote equity, and ensure the sustainable use of resources (Yang et al., 2020). The Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework also consider governance, institutions, infrastructure, and society, but they do so in the context of socio-ecological systems dynamics and the capacity of a system to absorb disturbance and reorganize (Cundhill et al., 2010; Stockholm Resilience Centre, n.d.; Yang et al., 2020).

### 3.4. Integration of Hard and Soft Infrastructures

Pagano et al. (2018) developed an integrated approach to assess resilience for hard and soft infrastructural systems in water distribution. They used a graph theory-based approach and social network analysis to model the complexity of interactions between infrastructures. This approach is unique to their framework and is not explicitly considered in the SEPLS model, the Resilience Alliance's Resilience Framework, or the Stockholm Resilience Centre's Framework. The SEPLS model, while not explicitly focusing on the integration of hard and soft infrastructures, does consider the interactions between various elements of a socio-ecological system, including both physical (hard) and social (soft) components (Pagano et al., 2018; Takahashi et al., 2022; Torralba et al., 2023) The Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework, on the other hand, focus more on the dynamics of socio-ecological systems and do not specifically address the integration of hard and soft infrastructures (Cundhill et al., 2010; Stockholm Resilience Centre, n.d.)

### 3.5. Consideration of Future Risks and Multiple Hazards

Afzal et al. (2020) highlighted the importance of considering future risks, stakeholder consultation, and multiple hazards in resilience assessment in power system resilience frameworks. They argued that resilience assessment should not only consider current risks but also anticipate future risks and uncertainties. The SEPLS model also considers future risks and multiple hazards, but it does so in the context of socio-ecological systems rather than power systems. It emphasizes the need for forward-looking strategies that can help socio-ecological production landscapes and seascapes adapt to future changes and uncertainties (Afzal et al., 2020; Takahashi et al., 2022; Tamberg et al., 2020; Yang et al., 2020). The Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework also consider future risks and multiple hazards, but they do so in the context of socio-ecological systems dynamics and the biophysical limits of the Earth system, respectively (Afzal et al., 2020; Cundhill et al., 2010; Stockholm Resilience Centre, n.d.)

### 3.6. Understanding of Socio-Ecological Systems Dynamics

The Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework both emphasize understanding the dynamics of socio-ecological systems. They focus on the capacity of a system to absorb disturbance and reorganize while undergoing change to retain its function, structure, identity, and feedbacks. The SEPLS model also considers socio-ecological systems dynamics, but it further integrates this understanding with a focus on the harmonious coexistence of people and their natural environment(Boafo & Ichikawa, 2016; Subramanian et al., 2017; Torralba et al., 2023; UNU-IAS, 2013; Yang et al., 2020). It emphasizes the need to understand and manage the interactions between various elements of a socio-ecological system, including the physical environment, biodiversity, cultural diversity, knowledge systems, and governance systems (Cundhill et al., 2010; Saja et al., 2019; Stockholm Resilience Centre, n.d.).

### 3.7. Adaptability to Different Contexts

The adaptability of a resilience framework to various contexts is crucial, especially given the diverse challenges faced by different socio-ecological systems across the globe. Designed to be applicable across various landscapes and seascapes, SEPLS model is inherently flexible, accommodating different ecological, social, and cultural contexts. Its emphasis on integrating various types of knowledge, including traditional, scientific, and local, ensures that it can be tailored to the unique characteristics and needs of different regions (Boafo & Ichikawa, 2016; Subramanian et al., 2017; Torralba et al., 2023; UNU-IAS, 2013; Yang et al., 2020). This adaptability is further enhanced by its focus on stakeholder participation, allowing local communities to shape the resilience assessment process based on their lived experiences and priorities.

The Resilience Alliance's Resilience Framework, while comprehensive, is more rooted in understanding the dynamics of socio-ecological systems. Its adaptability is somewhat limited by its primary focus on the capacity of a system to absorb disturbance and reorganize. While it provides a robust framework for understanding resilience, its application may require more adjustments to fit specific local contexts (Cundhill et al., 2010). The Stockholm Resilience Centre's Framework, with its emphasis on planetary boundaries, offers a global perspective on resilience. While this global view is essential, especially in the context of global sustainability challenges, its adaptability to local or regional contexts might be less straightforward. The framework's focus on biophysical limits of the Earth system means that it may need to be complemented with more localized knowledge and insights to be fully adaptable to specific contexts (Stockholm Resilience Centre, n.d.)

Saja et al. (2019), in their review of social resilience assessment frameworks, highlighted the need for adaptability to different contexts. They noted the challenges posed by inconsistencies in key concepts across different frameworks and emphasized the importance of having a resilience framework that can be tailored to various socio-cultural and environmental contexts (Saja et al., 2019)

In comparing all resilience frameworks, the Socio-Ecological Production Landscapes and Seascapes (SEPLS) model stands out among the resilience frameworks reviewed for several reasons. First, it takes a holistic approach, considering not just the physical environment but also the social, economic, and cultural aspects of landscapes and seascapes. This approach allows for a more comprehensive understanding of resilience in socio-ecological systems. Second, the SEPLS model emphasizes stakeholder participation and forward-looking strategies, which are critical for building resilience in the face of future changes and uncertainties. Third, the SEPLS model provides consistent key concepts, making it easier to interpret and apply in different contexts. Finally, the SEPLS model balances the consideration of various factors, including governance, institutions, infrastructure, society, economy, and the environment, providing a more rounded view of resilience. Therefore, the SEPLS model offers a comprehensive and adaptable framework for assessing resilience in socio-ecological production landscapes and seascapes.

While other frameworks offer valuable insights and approaches, they may lack the same level of adaptability. For instance, the Resilience Alliance's Resilience Framework and the Stockholm Resilience Centre's Framework, while providing robust frameworks for understanding resilience, may require more adjustments to fit specific local contexts. The SEPLS model's adaptability, clarity, and holistic approach make it a standout option for those seeking a comprehensive and community-centered resilience assessment framework.

## 4. The Socio-Ecological Production Landscapes and Seascapes Concept

### 4.1. Origin of the SEPLS Concept

Satoyama, a Japanese term, refers to a mosaic of different ecosystems such as secondary forests, farmlands, irrigation ponds, grasslands, and human settlements (Ichikawa, 2013; JSSA, 2010)) This type of landscape provides diverse land uses that offer benefits for people’s lives and agricultural production. Beyond provisioning services, the satoyama landscape also provides regulating services such as flood prevention, watershed conservation, landslide and erosion prevention functions, and pollination (Takeuchi et al., 2016). The various environmental conditions of the mosaic of ecosystems harbor more species across the entire landscape. The concept has been extended to satoumi, which encompasses marine and coastal ecosystems. Satoumi refers to the spatial structure of coastal areas and the use and management of fisheries resources within these areas.

These two concepts depict the relationship of the mutually beneficial interaction between humans and the environment, allowing for the sustainable use of resources. This satoyama-satoumi concept, internationally known as traditional socio-ecological production landscapes and seascapes (SEPLS), is a historical model for environmental stewardship and resource management that contributes to human well-being (Hashimoto & Nakamura, 2014; JSSA, 2010).

The Japan Satoyama-Satoumi Assessment (JSSA) focuses on the link between humans and different landscape ecosystems in Japan and how they interrelate with each other. It follows the framework of sub-global assessments developed by the Millennium Ecosystem Assessment. JSSA adopts the ecosystem services conceptual framework developed by MA due to the following reasons: (a) centrality of human well-being in considerations of ecosystem services, (b) recognition of the interdependency, synergy, and trade-offs between ecosystem services and human well-being, and (c) acknowledgment of different temporal and spatial scales that impact interdependency (Takahashi et al., 2022).

SEPLS represent harmonious human-nature interactions resulting in positive outcomes for both biodiversity and human well-being, thus implying synergies among multiple nature's contributions to people (NCP) are possible. In case studies of ten projects selected from biodiversity hotspots under the GEF-Satoyama Project, it was found that synergies in NCP exist within SEPLS and management interventions that enhanced these synergies were identified. Among the management options that enhanced NCP in SEPLS were food-centered approaches entailing organic agriculture, eco-labelling, branding and improved agricultural practices. Habitat-centered approaches included participatory biodiversity monitoring, ecosystem restoration, co-management and conservation agreements with landowners. Synergies in NCP were generated by integrating these interventions with enabling governance structures and through community empowerment (Takahashi et al., 2022)

## 4.2. Concepts and Characteristics of SEPLS

Socio-Ecological Production Landscapes and Seascapes (SEPLS) are dynamic mosaics of habitats and land and sea areas shaped by the interactions between people and the environment over time. These interactions not only maintain biodiversity but also provide a bundle of ecosystem services that contribute to human well-being ((Ciftcioglu, 2016; Gu & Subramanian, 2014)).

SEPLS are "*found in many parts of the world, of different socio-economic context, where humans are directly linked with nature through various forms of resource use, including primary industries, subsistence activities, tourism, and cultural uses"*(Gu & Subramanian, 2014). In SEPLS, biodiversity and ecosystems support humans by delivering ecosystems services such as food, fuels, shelter, cultural values, while in return, humans support biodiversity and ecosystems through managing the natural resources for its sustainable use (Subramanian et al., 2017).

The SEPLS concept underscores the importance of traditional knowledge, which is instrumental in building sustainable management strategies for the further development of the landscape. The socio-ecological characteristics of SEPLS vary depending on their location, as their sustainable use and management are influenced by the local inhabitants' traditional norms, beliefs, practices, and customs (Boafo et al., 2016; Kadoya & Washitani, 2011).

SEPLS is also characterized with enhanced biodiversity due to mosaic ecosystems that can support organisms. The SEPLS concept aligns with the core objective of the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES), which aims to understand ecosystem production, function, and services to balance conservation and development goals, integrate scientific findings into policies, and improve human well-being (Indrawan et al., 2014).

From a sustainability perspective, SEPLS shares the basic premise of socio-ecological systems and resilience thinking, which posits that social and ecological systems are interconnected, and adaptive management is necessary to address ecosystem changes (Gu & Subramanian, 2014). SEPLS not only provide ecosystem services for local communities but also for larger populations beyond their borders. The production and harvesting processes within SEPLS are influenced by external demands, pressures, and policy decisions at national and international levels (Gu & Subramanian, 2014; Hashimoto & Nakamura, 2014). SEPLS are dynamic in nature and are sustained through adaptive co-management regimes, with interlinkages amongst natural and cultural processes that operate on different time frames (Gu & Subramanian, 2014).

## 4.3. Changes in SEPLS

SEPLS across the globe have been experiencing a rapid decline due to a multitude of anthropogenic and natural drivers, jeopardizing their sustainability. These influential factors are largely dependent on the socio-economic context of each region (Gu & Subramanian, 2014; Ichikawa, 2013; JSSA, 2010).

The changes in SEPLS are primarily shaped by the interactions between people and nature. Several factors have been identified as drivers of these changes. Indirect factors include economics, culture and religion, science and technology, population, and public policy. Direct factors encompass changes in land use, underuse, overhunting/overharvesting, climate change, the introduction of non-native species, and pollution (JSSA, 2010).

These drivers can be further categorized into socio-political transformation, legal rights and autonomy, economic globalization, and demographic and socio-cultural changes (Gu & Subramanian, 2014). The manifestation of these drivers varies across different regions, as illustrated by the following case studies:

In Africa, SEPLS face threats due to interrelated natural and anthropogenic factors, including climate change, unsustainable resource extraction, population pressure, and governance and institutional issues. Changing rainfall and temperature patterns have resulted in water scarcity and severe impacts on rain-fed agricultural production, affecting food security. The increasing global demand for mineral resources and fossil fuels has led to the conversion of large tracts of rural landscapes into mining concessions, resulting in adverse impacts on the landscape (Boafo et al., 2016; Mapani & Kribek, 2012)

In Japan, particularly in the Noto Peninsula, the sustainability of SEPLS is threatened by rapid depopulation and an aging local community. These factors have led to the gradual collapse of the balance between humans and nature, causing the abandonment of farmland and forests, and increasing the incidence of human-wildlife conflict (Hashimoto & Nakamura, 2014)

In Cambodia, SEPLS are becoming uniform due to land use change. The 1990s saw a focus on timber production from high-value forests managed by private companies under large-scale forest concessions. This led to high levels of illegal logging and degradation of forest resources, exacerbated by conflicts over rights with local communities who traditionally used to collect natural resources from the concession forests (Ichikawa, 2013)

In the Lefke Region of North Cyprus, the mosaic of forest, maquis, agriculture, coast, and marine ecosystems plays a significant role in the production of ecosystem services. However, this mosaic is threatened by land use change due to the impacts of urbanization and land abandonment. Other factors such as low level of management, migration, lack of job opportunities, and an aging society have led to the transformation of the SEPLS of the Lefke Region (Ciftcioglu, 2016, 2017)

These case studies illustrate the complex interplay of factors contributing to changes in SEPLS. Policies on mining concession in Africa and forestry concession in Cambodia, for instance, have triggered the conversion of rural landscapes. Although these policies aim to improve livelihood and food security and reduce poverty, they have negative impacts on maintaining the SEPLS structures and dynamics (Indrawan et al., 2014) Changes in demography also affect land use change (Gu & Subramanian, 2014). The increasing population has impacted the unsustainable use of natural resources in Africa and the conversion of shifting agriculture to cash crops in Cambodia. Conversely, rapid depopulation and aging of the community have led to the abandonment of SEPLS in rural areas in the Lefke Region of North Cyprus and the Noto Peninsula of Japan.

## 5. The Candaba Wetlands, Pampanga, Philippines

### 5.1. Geographical Overview

The Candaba Wetlands, also known as the Candaba Swamp or Candaba Marsh, is a socio-ecological system that encompasses a diverse range of wetlands within the municipality. This area is recognized as a Key Biodiversity Area and is one of the three sites included in the Northwest Manila Bay regional grouping as reported in the Philippine National Report on Wetlands (2015). Geographically, the wetland is situated approximately 50 km north-north-west of Metro Manila, near the towns of Candaba in Pampanga and San Miguel and San Ildefonso in Bulacan, all in Central Luzon (DENR-PAWB, 2005; Juarez-Lucas et al., 2018; Melendres, 2014)

The Candaba Wetlands spans an area of 32,000 hectares, which reduces to 10,000 hectares during dry seasons. This seasonal wetland comprises a complex of freshwater ponds, wetlands, and marshes, surrounded by seasonally flooded grassland, arable land, and palm savanna on a vast alluvial flood plain. The majority of the wetland is privately owned, which presents unique challenges for conservation efforts (Canning et al., 2023)

### 5.2. Ecological Dimension

#### 5.2.1. Natural Flood Retention

The Candaba Wetlands serve as a natural flood retention basin, holding the wet season overflow from the Maasim, San Miguel, Garlang, Bulu, and Penaranda Rivers, and draining into the Pampanga River (DENR-PAWB, 2005; Juarez-lucas et al., 2016; Juarez-Lucas et al., 2018; B. Shrestha et al., 2014; B. B. Shrestha et al., 2014). It functions as a retarding basin, absorbing most flood flows from the eastern sections of the basin and overflows from the Pampanga River via the Cabiao floodway (Garcia, 2010; B. B. Shrestha et al., 2014). This flood control function is similar to the green infrastructure practices observed in Japan, where flood-control basins are used to reduce flood risk while also providing habitat for biodiversity (Ishiyama et al., 2022)

#### 5.2.2. Habitat to Biodiversity

The Candaba Wetlands bolster a seasonal fishery, aligning with the onset of monsoon floodwaters. Despite the predominant agricultural use of the flood plain, the native vegetation is characterized by water lilies, lotus, water hyacinths, and aquatic reeds. Additionally, there are sporadic patches of *Nypa fruticans* and mangroves in adjacent areas (DENR-PAWB, 2005). In a study by Garcia (2010), 18 aquatic species, predominantly *Cyprinids*, were identified in specific regions of the wetlands. The wetland is also a crucial habitat for migratory waterfowls, particularly during October and November. During these months, the wetland becomes a temporary home for 5,000 to 10,000 migratory birds, including egrets, wild ducks, herons, and kingfishers. This influx coincides with the icy conditions in the Northern Hemisphere. Additionally, the wetland provides sanctuary for diverse wildlife, including small mammals, reptiles, and amphibians. The ecological richness of the Candaba Wetlands can be paralleled with the high Andean wetlands of Peru, which are celebrated for their ecosystem services and contribution to local economies (León et al., 2021).

### 5.2.3. Historical and Cultural Importance

The Candaba Wetlands, with its rich biodiversity and ecological significance, also holds historical and cultural importance. In 1951, the expansive depth of the wetlands and the nearby wilderness of Mount Arayat provided refuge for the HUKBALAHAP, a communist movement in the Philippines (Fifield, 2014). Furthermore, an archaeological site was uncovered in Donya Simang, situated at the heart of the Candaba Wetlands. This discovery was made by Melendres (2014) and his colleagues during a bird-watching expedition. The site's exposure was a result of the construction of an elevated road leading to a bird camp. Among the artifacts found were indigenous undecorated earthenware, believed to date back to before 1000 AD. Additionally, oriental trade ceramics from China, dating from 1300 – 1600 AD, brown glazed stoneware jars from the 13th to 14th century, and blue and white porcelains from the Hongzi period in the late 15th to 16th century were also discovered.

### 5.2.4. Tourism

The Candaba Wetlands is a favored destination for both local and international bird watchers and naturalists. Its proximity to Metro Manila and its rich biodiversity make it an ideal spot for nature-oriented outdoor recreation and conservation education. The wetland is renowned for its duck products, particularly salted eggs and the exotic delicacy "balut" or boiled unhatched duck eggs. Recognizing the wetland's dual role as a fishing ground and a stopover for migratory birds, the Local Government Unit of Candaba initiated the “Ibun-Ebun (Bird-Egg) Festival” (Melendres, 2014). Such initiatives highlight the potential of the wetlands for ecotourism. In fact, protected areas, due to their recognized natural, ecological, and cultural values, are valuable resources for the rural economy and play a crucial role in the tourism industry (Grgić et al., 2021). Adopting a sustainable tourism model for the Candaba Wetlands can not only elevate its stature but also champion its preservation (Amara, 2017)

## 5.3. Agriculture and Fisheries Dimension

### 5.3.1. Agriculture and Wild Fisheries

At the municipal level, agriculture and fisheries are the primary sources of income for 70% and 13% of the total households, respectively. During the dry season, from late November to April, the area is converted into rice fields and watermelon plantations. During the rainy season, the impoundment is used as a fishpond and supports a seasonal fishery (Garcia, 2010; Juarez-lucas et al., 2016). Most of the privately-owned flood plain has been converted to agricultural and residential land except for the core area of approximately 500 ha. Since floods are recurrent in the area, livestock and poultry production in Candaba Wetlands are slowly increasing. The locals raise carabaos or water buffaloes, pigs, chickens, ducks, goats, sheep, and cows.

### 5.3.2. Cropping Season

Cropping season varies within the three subdivisions of the municipality. In Riverside areas, farmers only experience one cropping season which falls January to April or May due to imminent flooding during months of June to November. The farmers from Tagalog and Kapampangan regions enjoy two cropping seasons. The first cropping starts from January to April or May and the second cropping falls from October to December.

### 5.3.3. Farmers and Fisherfolks

The 2018 data from the Municipal Agriculture Office listed 7, 519 farmers were recorded during dry season and 5,492 during the wet season. Barangay Mandili had the highest number of farmers in both seasons. A total of 2,434 fisherfolks were also recorded in Candaba and mostly from Barangays San Agustin, Mandili and Bambang.

The sustainability of these agricultural and fisheries practices is closely linked to the health of the Candaba Wetlands ecosystem. As Ramachandra (2022) notes, the integrity of the catchment area, which includes vegetation, plays a crucial role in maintaining soil moisture and water availability, both of which are essential for farming and fisheries. In areas with more than 60% vegetation of native species, streams are perennial, and soil moisture is higher, facilitating the farming of commercial crops with higher economic returns to the farmers. In contrast, streams are intermittent or seasonal in catchments dominated by monoculture plantations or with vegetation cover lower than 30%. This highlights the need to maintain ecosystem integrity to sustain water availability and, by extension, agricultural and fisheries productivity in the Candaba Wetlands.

## 5.4. Social Dimension

### 5.4.1. Demography

The Municipality of Candaba had a total population of 102,400 and a total of 20,211 households with a mean household size of five members as of the 2010 Philippine Census. The majority, 67%, of the population resided in rural areas (Juarez-lucas et al., 2016; Juarez-Lucas et al., 2018) This rural lifestyle, often characterized by close-knit communities and reliance on natural resources, can contribute to a unique social dynamic that is integral to the identity of the Candaba Wetlands (Rao. M. & Pasala, 2019).

### 5.4.2. Economic Activities

The Municipal Treasury Office recorded a total of 613 establishments registered in Candaba in 2018, with 25% being new. These establishments were predominantly located in Barangay Bahay Pare and the Poblacion area, which are the most populous and commercial areas, respectively. The service sector, mainly engaged in retail trade and general services, comprised a significant portion of the economy. The presence of 13 associations and 15 cooperatives also indicated a strong sense of community and mutual support among the residents (Antipova & Momeni, 2021).

### 5.4.3. Health

Health services in Candaba were provided by one hospital/infirmary, three rural health units, 31 barangay health stations, and seven private clinics. Acute respiratory infection was the leading cause of morbidity, followed by hypertension, diabetes mellitus, and urinary tract infection. The availability and accessibility of these health services are crucial for the well-being of the residents, particularly the elderly, who require more frequent health care services (Mohammadi et al., 2021)

The social dimension of the Candaba Wetlands is a complex interplay of demographic, economic, and health factors. Understanding these factors is crucial in planning and implementing sustainable development initiatives in the area (Estebsari et al., 2020)

## 6. Conceptualizing the Socio-Ecological Resilience of Candaba Wetlands

The Socio-Ecological Production Landscapes and Seascapes (SEPLS) framework offers a unique approach to understanding socio-ecological systems, treating both social and ecological dimensions with equal depth (Binder et al., 2013; Ciftcioglu, 2017) which is definitely applicable to Candaba Wetlands. Recognizing the intricate and dynamic nature of SEPLS, indicators have been developed to capture the essential elements that underpin a resilient landscape. While a set of indicators exists, they are not rigid measurements but rather a guide to understand and bolster SEPLS resilience (UNU-IAS, 2013; UNU-IAS et al., 2009; UNU-IAS & IGES, 2015). These indicators can be adapted and localized based on the specific SEPLS in question.

The socio-ecological resilience of Candaba Wetlands through the lens of SEPLS model encompasses four primary areas: (1) ecosystem protection and maintenance of biodiversity; (2) agricultural biodiversity; (3) knowledge, learning and innovation; (4) social equity and infrastructure. But these areas can be further grouped according to its respective dimension.

a. Ecosystem Dimension

Ecosystem protection and maintenance of biodiversity could enhance the resilience of an ecosystem. The diversity and interactions of species in Candaba Wetlands reflects the ecosystem health (Fischman, 2004). Biodiversity, encompassing variation from within species to across landscapes, is crucial in the resilience of underpinning ecosystem functions and the services(Convention on Biological Diversity, 1992; Levin, 2013; Oliver et al., 2015). By protecting the ecosystem and maintaining the biodiversity, the community settling in the Candaba Wetlands could gain from the ecosystem services which are either sustained or degraded by the human practices and the institution that regulate the use of natural resources (Yao et al., 2015). Spatial heterogeneity and multifunctionality of the landscape create a mosaic of habitats, thus, increasing the biodiversity (Benton et al., 2003; Oliver et al., 2015; Sutti, 2016). Designating protected areas is also critical in conserving biodiversity as this measure safeguard not only the species, but also the habitat (BMB, 2015; CBD, 2008). The rate of recovery from the extreme environmental and climate change-related stresses and shocks is also vital as this will determine the ability of the Candaba Wetlands to bounce back to its original state (Adger, 2005; UNU-IAS, 2013).

b. Agricultural Dimension

The agricultural biodiversity in Candaba Wetlands creates the nexus of its ecosystem health and the community(UNU-IAS, 2013). This is linked by the array of functions such as maintenance of agroecosystem functions, sustainable production of food and other agricultural products, and biological support to production (Convention on Biological Diversity, 2013; Cromwell et al., 1999; FAO, 2019; GIZ, 2014). Thus, it is essential to maintain, document and conserve the wetland's agricultural biodiversity. To conserve the Candaba Wetlands, a range of different measures such as on-farm management, restricting farming intensity, prevention of farmland abandonment, establishment of gene bank, botanical garden, agricultural research stations and tissue culture collections, and following eco-agriculture practices (Fransiska et al., 2015; GIZ, 2014; Kleijn et al., 2011) could be conducted. The agricultural biodiversity could also be improved by involving and recognizing the role of the farmers in conservation (Abay et al., 2009), thereby, also have a positive impact in the adaptive capacity of Candaba Wetlands (Dennis, 2015). Horizontal networks such as intercommunity resource trade could also enhance the resilience to perturbation, particularly climate variability.

c. Social Dimension

The social dimension of Candaba Wetlands encompasses knowledge, learning and innovation; and social equity and infrastructure. The resilience of a community is strengthened by learning from different knowledge systems such as traditional and local adaptation strategies, customs, agricultural traditions, local languages, cultural values, and social institutions(UNU-IAS et al., 2009). Though the local knowledge is considered outdated, local knowledge is built upon the practical knowledge of the past experience and delivered from skilled generations (Panpakdee & Limnirankul, 2018). These knowledge systems that shaped the Candaba Wetlands is strongly linked the community and ecosystem. Maintenance of the local knowledge is significantly anchored by the ability of the community to document local knowledge (Ifejika Speranza et al., 2014b; Panpakdee & Limnirankul, 2018), access and exchange of local knowledge (Ifejika Speranza et al., 2014b; Panpakdee & Limnirankul, 2018; Subramanian et al., 2017), transmit local knowledge to younger generations (Elgar, 2013; Panpakdee & Limnirankul, 2018; UNU-IAS, 2013), uphold cultural traditions related to biodiversity(Ducusin et al., 2019; UNU-IAS, 2013), interact with the landscape, use of terminology or indigenous languages(UNESCO, 2003), and maintain diversity of local food system(Bioversity International, 2019) and local medical system(Alves & Alves, 2011; Nascimento et al., 2016).

The resilience of Candaba Wetlands is also reliant on the availability of and access to functioning social infrastructures, such as communication, health, and education. The resilience of the SEPLS could also improve with effective local resource governance with efficient institutional devolution and institutional arrangements (Senga, 2001; World Bank, 2003) that distinguishes property rights and autonomy in relation to land and resource management (Young, 2011). Fostering gender equality could also build and enhance resilience in the community as the women's leadership and decision-making are empowered and recognized (Chanamuto & Hall, 2015; Collord, 2018; Jenson, 2015). Resilience in the Candaba Wetlands is also dependent on the adaptive mechanism to disasters (UNISDR, 2015) as flooding is recurrent in the area. As a hotspot for migratory birds, ecotourism also has a contribution to resilience of the wetland (Hall, 2013) as this nature-based type of tourism was considered a solution to the disconnect between sustainability and development (Kiper, 2013).

In conclusion, the social dimension of the Candaba Wetlands is a complex interplay of demographic, economic, and health factors. Understanding these factors is crucial in planning and implementing sustainable development initiatives in the area (Estebsari et al., 2020). Accordingly, a set of suitable resilience assessment indicators for the ecological, social and agricultural systems of the Candaba Wetlands was developed by reviewing relevant references. The suitable indicators are detailed in table below:



Table 1. Resilience Indicators for Candaba Wetlands

| **Area** | **Indicator** | **Variable** | **References** |
|---|---|---|---|
| Ecosystem Dimension | | | |
| Ecosystem Protection and Maintenance of Biodiversity | Flora and fauna | Degree of decline in biodiversity | (Fischman, 2004; UNU-IAS, 2013) |
| | Spatial heterogeneity and multifunctionality | Number of ecosystems and land uses | (Benton et al., 2003; Sutti, 2016; UNU-IAS, 2013) |
| | Areas protected for cultural importance | Number of designated protected area | (UNU-IAS, 2013) |

| Area | Indicator | Variable | References |
|---|---|---|---|
| | Rate of recovery | Length of recovery time | (Adger, 2005; UNU-IAS, 2013) |
| Agricultural Dimension | | | |
| Agricultural Biodiversity | Crops cultivated | Number of crops cultivated | (UNU-IAS, 2013) |
| | Animals domesticated | Number of animals domesticated | (Matsushita et al., 2016; UNU-IAS, 2013) |
| | Maintenance of agricultural biodiversity | Use of local varieties and breeds | (Convention on Biological Diversity, 2013; UNU-IAS, 2013) |
| | Documentation and conservation of agricultural biodiversity | Degree of documentation and conservation of agricultural biodiversity | (Fransiska et al., 2015; GIZ, 2014; Kleijn et al., 2011; UNU-IAS, 2013) |
| | Innovation in agricultural biodiversity management | Degree of community reception to changes | (Abay et al., 2009; UNU-IAS, 2013) |
| | Access and exchange of agricultural biodiversity | Presence of networks of exchange and access of agricultural biodiversity | (UNU-IAS et al., 2009) |
| Social Dimension | | | |
| Knowledge, learning and innovation | Transmission of local knowledge | Degree of intergenerational transmission of knowledge | (Campilan, 2002; Elgar, 2013; Panpakdee & Limnirankul, 2018; UNU-IAS, 2013) |
| | Number of generations interacting with the landscape | Number of generations interacting with the landscape | (Elgar, 2013; UNU-IAS, 2013) |
| | Cultural activities related to biodiversity | Presence of cultural activities and community involvement | (Ducusin et al., 2019; UNU-IAS, 2013) |
| | Practices of documentation and exchange of knowledge | Presence of institutions and systems for documentation and exchange of knowledge | (Ifejika Speranza et al., 2014a; Panpakdee & Limnirankul, 2018; UNU-IAS, 2013) |
| | Use of local terminologies | Degree of use of local terminologies | (UNESCO, 2003; UNU-IAS, 2013) |
| | Practice of traditional healing methods | Degree of practice of traditional healing methods | (Nascimento et al., 2016) |
| | Maintenance of local food diversity and system | Degree of local food diversity and system | (UNU-IAS, 2013; Wahlqvist, 2003) |
| Social Equity and Infrastructure | Dependence on natural resources | Degree of dependence on natural resources | (UNU-IAS, 2013) |
| | Local resource governance | Presence of institutions and programs governing the area | (Senga, 2001; UNU-IAS, 2013) |

| Area | Indicator | Variable | References |
|---|---|---|---|
| | Gender equality | Degree of women's participation in community activities | (Chanamuto & Hall, 2015; Jenson, 2015; UNU-IAS, 2013) |
| | Clear ownership and autonomy in relation to land resource management | Degree of land tenure and autonomy | (DFID, 1999; UNU-IAS, 2013) |
| | Social infrastructures | Presence and access to social infrastructures | (DFID, 1999; UNU-IAS, 2013) |
| | Health care | Access to health care | (UNU-IAS, 2013) |
| | Livelihood diversity | Presence of on-farm and off-farm livelihood | (DFID, 1999; Panpakdee & Limnirankul, 2018; UNU-IAS, 2013) |
| | Access to credit and loans | Presence and access to credit and loans | (DFID, 1999; UNU-IAS, 2013) |
| | Local disaster management | Presence of local disaster management plans and equipment | (Cutter et al., 2010; UNISDR, 2015) |
| | Ecotourism | Presence of ecotourism policies and activities | (Gallaher, 2007; Kiper, 2013) |



## 7. Conclusion

This paper delves into the socio-ecological resilience of the Candaba Wetlands, anchoring its analysis on the Socio-Ecological Production Landscape and Seascape (SEPLS) framework. The SEPLS model, renowned for its participatory nature, offers a comprehensive lens to decipher the intricate interplay between the wetland's ecological and social systems. By adopting the SEPLS approach for the Candaba Wetlands, we aim to harness its inherent participatory methodology to glean insights into the dynamics of these intertwined systems.

One of the salient features of the SEPLS model is its recommendation to employ the Likert scale for assessment. This scale offers a straightforward method to quantitatively encapsulate individuals' perceptions and viewpoints (Ifejika Speranza et al., 2014; UNU-IAS, 2013). Beyond merely capturing impressions, this measurement scale can be instrumental in monitoring the roles and contributions of various stakeholders. Specifically, it can track their efforts in bolstering the resilience of the wetland's socio-ecological system, especially during times of disturbances or perturbations (Jain, 2012).

Furthermore, the SEPLS model underscores the pivotal role of knowledge systems. In the context of the Candaba Wetlands, the anthropogenic activities and their subsequent impacts are intrinsically linked to the knowledge and learning paradigms of the local inhabitants. This recognition of the knowledge system's significance accentuates the need for continuous learning and adaptation, especially in the face of evolving challenges.

The SEPLS approach fosters collaboration. By leveraging this model, key stakeholders from the Candaba Wetlands can convene, fostering a collaborative spirit. Such collaboration can pave the way for the joint formulation of policies and tools that resonate with the multifaceted dimensions of the wetland, ensuring a holistic approach to its conservation and sustainable development.

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