Philippine Journal of Science
153 (4): 1393-1402, August 2024
ISSN 0031 - 7683
Date Received: 20 Feb 2024

Understanding Socio-Ecological Complexity of Mangrove-Crocodile-Fisher System of Bugsuk Island, Balabac, Palawan, the Philippines

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The mangrove forest in Palawan has the most extensive distribution in the Philippines. The fisher community's perception of the mangrove forest as a known habitat for saltwater crocodiles (*Crocodylus porosus*) and its fishery benefits in Bugsuk Island were gathered using a participatory systems mental modeling framework for the coastal social-ecological system. From the causal loop diagram, six reinforcing and one balancing feedback loop were derived. The respondents observed a positive growth in the interaction between mangroves and crocodiles in Bugsuk Island, with both populations expanding and providing support to fishery resources. Bugsuk Island represents a unique diversity with great potential for resource conservation and economic benefit.

Keywords: crocodiles, fishery management, mangroves, SESAMME, systems thinking

INTRODUCTION

The island of Palawan holds the biggest share in mangrove extent distribution (Long and Giri 2011) in the Philippines. As such, Palawan was declared a mangrove swamp forest reserve in 1981 by Presidential Proclamation No. 2152 (Dangan-Galon *et al*. 2016). This vast mangrove resource supports Palawan's' continually growing population, which is very much dependent on its coastal resources. Despite facing various threats from conversion, direct collection, and encroachment (PCSD 2014), Palawan's mangrove area has shown a recorded 5.55% annual increase from 1992–2010, increasing from 50,602–63,532 ha (PCSD 2015). Mangrove forests are significant coastal resources that are vital in providing ecological, cultural, and socio-economic benefits (Walters *et al*. 2008; Brander *et al*. 2012; Barbier 2015; Himes-Cornell *et al.* 2018). This also contributes to the food web complexity and energy transfers (Kandasamy 2012). Socio-economic contributions range from sources of traditional medicine, versatile forest and timber products, and fishery resources (Govindasamy 2011; UNEP 2014). The mangrove forest in general and the mangroves of the province, in particular, are known wildlife habitats (Primavera 2004) that support the enhancement of fisheries as breeding grounds, nurseries, and habitats for aquatic organisms (Anneboina and Kumar Kavi 2017).

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The Palawan's mangrove forests serve as home to numerous threatened endemic terrestrial wildlife fauna, as well as aquatic organisms like crustaceans, bivalves, gastropods, and other invertebrates (Primavera 2004). Mangrove forests in Palawan likewise contribute value to cultural recreation and tourism (Spalding and Parrett 2019) with a total economic value of USD 685.8/ha in 2013 (Carandang *et al*. 2013). Saltwater crocodiles still exist in the mangrove forest of southern Palawan; however, their population is under threat due to the increasing human population and habitat fragmentation (Regoniel 1992; Manalo 2004). While the most popular theory suggested by Fittkau (1970) on the ecological role of crocodilians implies that the decrease in crocodilians can be linked to the reduction of fishery stocks, this notion has yet to be proven.

In the study of Manalo *et al.* (2016), the average spotlight count density in 19 rivers on the mainland and nearby islands of southern Palawan is 0.47 individuals/km of river surveyed. The highest relative density was observed in Bugsuk Island in the Balabac Group of Islands with a density of 3.99 individuals/km, where the river is associated with mangrove and beach forest ecosystem. Palawan's river and creek systems have an estimated population of 2,640 individuals. Bugsuk Island alone has an additional 3,000 individuals (CITES 2022).

Although mangroves have been known to improve fishery productivity (Hutchison *et al.* 2014), the presence of crocodilian species in river tributaries also contributes to the increased fish stocks (Fittkau 1970; Bucol *et al.* 2014). It is also noted that Bugsuk River is an exceptional crocodile habitat that has remained intact and free from human pressure due to its private nature (Corvera *et al*. 2017). The abundance of fish and crocodiles is noticeable in the northern part of the island. According to a review of the ecological role of crocodilians popularized by Fittkau (1970), the theory was considered more of a myth, speculative, and anecdotal than scientific. It had little to no impact on aquatic productivity, as stated in various studies conducted by Gorzula (1987), Webb (2002), Somaweera *et al.* (2020), and Bucol *et al*. (2020). However, the fishing community in Bugsuk Island is well aware of the impact of crocodiles on fisheries production in mangrove ecosystems and surrounding waters.

A focus group discussion (FGD) is conducted to gather and analyze community inputs on the condition of coastal resources, coastal-related activities, perceived threats or pressures, and local management decisions. During the discussion, the community's perception of the relevance of mangrove forests as a resource, crocodile habitat, and fishery productivity is explored. The consultation is supported by an iPad-based application called socio-ecological systems application for mental model elicitation (SESAMME) to capture the community's mental model of the coastal community and the interactions among its components (Richards *et al.* 2016). This exercise helps the community visualize the different components of the ecosystem and how they interact with each other through systems dynamics (Richards *et al.* 2016; CCRES 2018). The results from the mental model-building process can provide a clear picture of the relationship between the various variables, which can help identify locally crafted solutions to current fishery challenges if needed.

The primary goal of this study was to elicit stakeholders' mental model about the structure of a coastal social-ecological system of the mangrove-crocodile-fisher interaction in Bugsuk Island. Furthermore, the study aimed to identify the causal loop diagram (CLD) and polarities of interconnections of fishery resource variables that form feedback loops using the SESAMME. The outcomes were then interpreted as the realities and interactions between variables in dynamic behavior, demonstrating the polarities of the connections that represent the direction of correlation between two connected variables (cause and effect).

MATERIALS AND METHODS

Study Site

This study was carried out on the Island of Bugsuk, the largest among the six main islands in the Municipality of Balabac, Province of Palawan (PCSD 2015) (Figure 1). Approximately, there were 2,123 individuals residing on the Island with an average of five persons per household (PSA 2016).

The 8,857.99 ha of the northern part of the island is covered by a water leased agreement for pearl hatchery and culture. The management of these waters is in place, resulting in the protection of the island from various kinds of unsustainable practices. Strict protection sites are maintained while allowing utilization for sustenance in allowable areas.

The fringe mangrove areas of Bugsuk are concentrated in the west and northwest parts of the island and are composed of nine mangrove species dominated by *Rhizophora mucronata* and *Rhizophora apiculata* with extensive canopy formation. Strips and pockets of mangroves are also found in the estuarine channel, leading to the brackish marsh associated with herbaceous woody grasses and mixed lowland forest.

Data Collection and Gathering

Two separate FGD workshops were conducted in Bugsuk

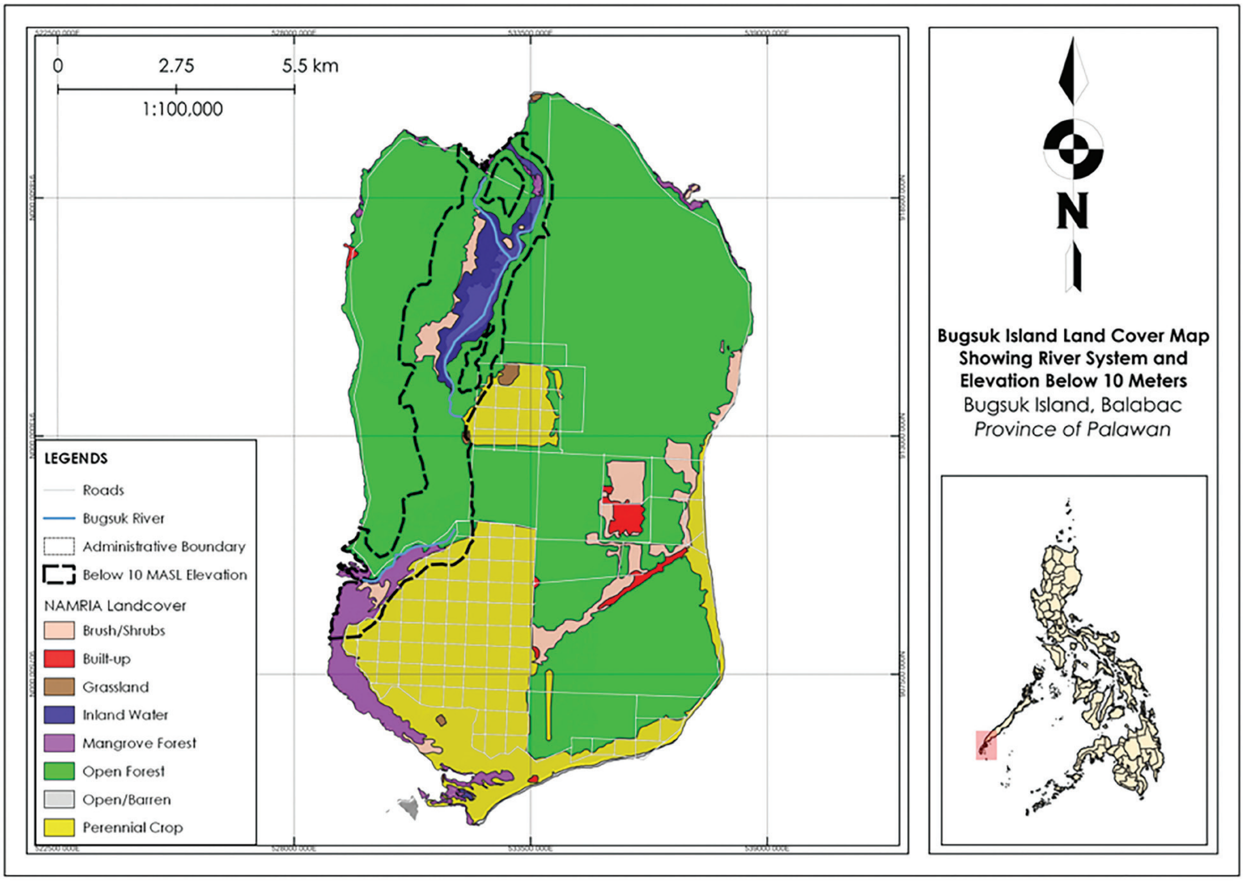

Figure 1. Bugsuk Island showing land cover map with river system and elevation below 10 m.

Island, Balabac, Palawan on 27–28 Oct 2019. A research Gratuitous Permit No. 2019-24, dated 24 Jul 2019, was obtained from the Palawan Council for Sustainable Development (PCSD) allowing for social data collection. Additionally, free and prior informed consent (FPIC) was obtained from the local government unit of the community before the consultation. The FPIC is necessary to comply with ethical research standards under the Indigenous People's Rights Act or Republic Act No. 8371. This ensures that the rights of the Indigenous Communities are respected during such activities.

A total of 43 respondents engaged in local fishing activities or serving either as local leaders or a respected elder in the community were collected to represent the respondents. The group is then divided into the governing and governed groups. The governing group was composed of administering authority – including local community leaders, IP leaders, community elders, and pearl farm officials. On the other hand, the governed group was composed of public partners such as fisherfolks, farmers, women's groups, and other community members. The decision to group participants separately was a necessary measure to ensure the free expression of opinions, which would have been hindered if both groups had been consulted together.

The data collection process commenced with the presentation of resource mapping tools, an explanation of consultation approaches, sharing of information on resource use patterns, and community perceptions. The "rich picture" elicitation mapping process was presented to the participants using the user-friendly SESAMME, an iPAD application tool for participatory process developed through the World Bank-funded project titled "Capturing Coral Reef and Related Ecosystem Services" (Richards *et al.* 2016). The pre-loaded SESAMME base map was used in developing a "rich picture" map with reference points showing the island boundaries, settlement areas, pearl farm structures, road networks, and inland water bodies. To direct the consultation towards the research question, a guide question was presented on the perceived relationship between the mangrove forests, crocodiles, and fisheries at Bugsuk Island.

The identification of the local activities, resources (effect), and pressures (cause) in the SESAMME library icons were related to the mangrove-crocodile-fisher system for Bugsuk Island. Interactions between the icons were determined, as well as the direction of causality specified as a negative or positive polarity. The final part of the discussion focuses on the decisions to address the perceived issues identified by the stakeholders.

Data Analysis and Interpretation

In this study, the SESAMME was used as the central engagement to elicit stakeholders's mental model about the structure of a coastal social-ecological system of the mangrove-crocodile-fisher system of Bugsuk Island. Outcomes of the SESAMME rich picture mapping were coalesced into a CLD (Haraldsson 2014) using the systems software Vensim (www.vensim.com) in order to create a single representation of the system. This presents the realities and interaction between variables in a dynamic behavior showing the polarities of the connections representing the direction of correlation between two connected (cause to effect) variables (Haraldsson 2014).

The polarities of interconnections whether a reinforcing or balancing feedback loop are determined when there is a chain of connected variables that forms a "feedback loop." A reinforcing loop was distinguished by having an even number of negative polarities or zero polarities, whereas balancing loops have an odd number of negative polarities. The identifying feedback loops are fundamental to the systems approach because these loops help explain the behavior of the system. Specifically, a reinforcing loop reflects a part of the system that promotes change, characteristically as exponential growth or exponential decline, and is always a temporary state of a system. A balancing loop resists change and instead pushes the system toward some equilibrium. It is the combination of these two types of feedback loops that results in the non-linear behavior of the system.

RESULTS

The governing and the governed groups have perceived a positive relationship between mangroves and crocodiles in increasing fish biomass. The coastal resources identified during the FGDs have been grouped and categorized according to the focus of this paper on the mangrove-crocodile-fishery system.

Coastal Resources Identification

The identified coastal resources included mangrove forests, saltwater crocodiles, and breeder milkfish, which form the main part of the social-ecological system (Table 1). The presence of the wild population of breeder milkfish has been a unique fishery resource closely associated with crocodiles, sharing the same space in the marsh. Other resources that were identified are seagrasses and seaweeds, demersal and pelagic fishery resources, shellfish, crustaceans, and coral reefs. The governed group identified some resources that were overlooked by the governing group. Subsequent discussion revealed that seaweed farming holds economic significance, and the beach serves ecological purposes beyond swimming such as being a marine turtle nesting site.

Table 1. Coastal resources and condition identified during the two FGDs.

Resources	Location	Condition
Mangrove forest	Surrounding the island	Good
Seagrasses	Surrounding the island	Good
Seaweeds	Surrounding the island	Good
Breeder milkfish	Inside marsh	Good
Beach turtle nesting site	South eastern side of the island	
Aquatic fishery resources		
Demersal and pelagic fish	Surrounding the island	Good
Shellfish	Surrounding the island	Good
Crustaceans	Mangrove area	Good
Saltwater crocodiles	Bugsuk river and marsh	Good
Coral reef	Surrounding the island	Good
	Western side of the island	Good
	Northern side of the island	Fair
	Eastern side of the island	Poor

The stakeholders from both FGDs perceived that the current state of many of the identified resources was in "good" condition. Moreover, the governing group noted that the coral reef on the western side of the island was in good condition, whereas the coral reef areas on the north and east sides were fair and poor, respectively. It is widely recognized that a healthy coral reef plays a crucial role in protecting mangroves from the damaging impact of strong ocean waves. Without mangroves, this highly productive ecosystem would inevitably collapse due to sedimentation. The governing group identified the entire fringing reefs on the island to be in a "good" state.

Interactions between Variables

There were 11 activities identified to be linked with resources and pressures (Table 2). Both FGD groups perceived a negative polarity interaction on resource use related to any of the fishing practices and had a positive interaction on pressures. The respondents observed that the presence of a pearl farming operation had a positive impact on all resources and did not exert any environmental pressure. Pearl Farm's implementation of a restrictive approach to all unsustainable anthropogenic activities has been seen to be an effective solution in improving coral health and increasing the resistance of the reefs to bleaching events.

In terms of activities that connect to pressures, unsustainable fishing practices were perceived to have a direct relationship with the effects of coral bleaching.

Table 2. Activity interactions to resources and pressures with their polarities.

Activities	Resources (effect)[a]	Pressures (cause)[b]
Non extractive practice		
Pearl farm operation	+	–
Gleaning	–	+
Seaweeds farming	–	+
Swimming	–	+
Tourism	–	+
Sustainable fishing practice		
Sustenance fishing	–	+
Unsustainable fishing practice		
Dynamite fishing	–	+
Cyanide fishing	–	+
Compressor fishing	–	+
Illegal indigenous fishing	–	+
Practice using plant extract	–	+

[a]Resources is the effect the interaction to the environment
[b]Pressure is cause of the interaction to the environment

Livelihood activities of fishing, seaweed farming, gleaning, and pearl farming were perceived to have a positive relationship with the population, whereas recreational activities (swimming and tourism) were perceived to have a positive relationship with waste production.

The respondents connected the pressures to various activities, which all have negative polarities. The four pressures were perceived to have negative relationships with fishing, gleaning, pearl farming, seaweed farming, tourism, and swimming activities (Table 3). As such, the governing workshop participants highlighted that increasing sea surface temperature causes high mortality of pearl oysters. All of the identified pressures were perceived by the participants to be negatively related to the aquatic resources. The respondents believed that dynamite fishing, the increasing volume of waste, and the increasing population were harmful to all the resources. Cyanide fishing, gill net fishing, the use of baby trawl, and the use of indigenous plant extracts negatively affect various fishery resources.

Table 3. Pressure to resources and activity interactions with their polarities.

Pressures	Resources	Activity
Climate change	–	–
Coral bleaching		
Increasing SST		
Garbage accumulation and disposal	–	–
Increasing human population	–	–

Causal Loop Development

The developed mental models reflected in a CLD system showed a total of seven loops forming the total FGD CLD (Table 4). A potential missing link could be the loop between fishing and the management of aquatic fishery resources, as fish mortality contributes to a decline in the available fish population. More intense fishing depletes the population pushing the population further down. However, because of local enforcement of conservation policies, this will again balance, thereby increasing fish recruitment. According to Macusi *et al*. (2017), fishers from General Santos City have an 80% likelihood of changing their fishing strategy when their catches decline. With similar situations through time, the balancing relationship would normally occur.

The loops in the CLD are interacting and are affected by external factors such as unsustainable fishing practices, climate change, increasing population, waste generation, fishing, and pearl farm operation (Figure 2). It was noticeable to the respondents that the island's

Table 4. Identified feedback loops of the CLD derived from the FGDs.

Loop	Description
R1	Mangrove forest → Saltwater crocodile → Mangrove forest
R2	Aquatic fishery resources → Saltwater crocodile → Aquatic fishery resources
R3	Aquatic fishery resources → Mangrove forest → Saltwater crocodile → Aquatic fishery resources
R4	Other wildlife → Aquatic fishery resources → Other wildlife
R5	Other aquatic flora → Other wildlife → Other aquatic flora
R6	Mangrove forest → Other wildlife → Mangrove forest
B1	Saltwater crocodile → Milkfish breeders → Saltwater crocodile

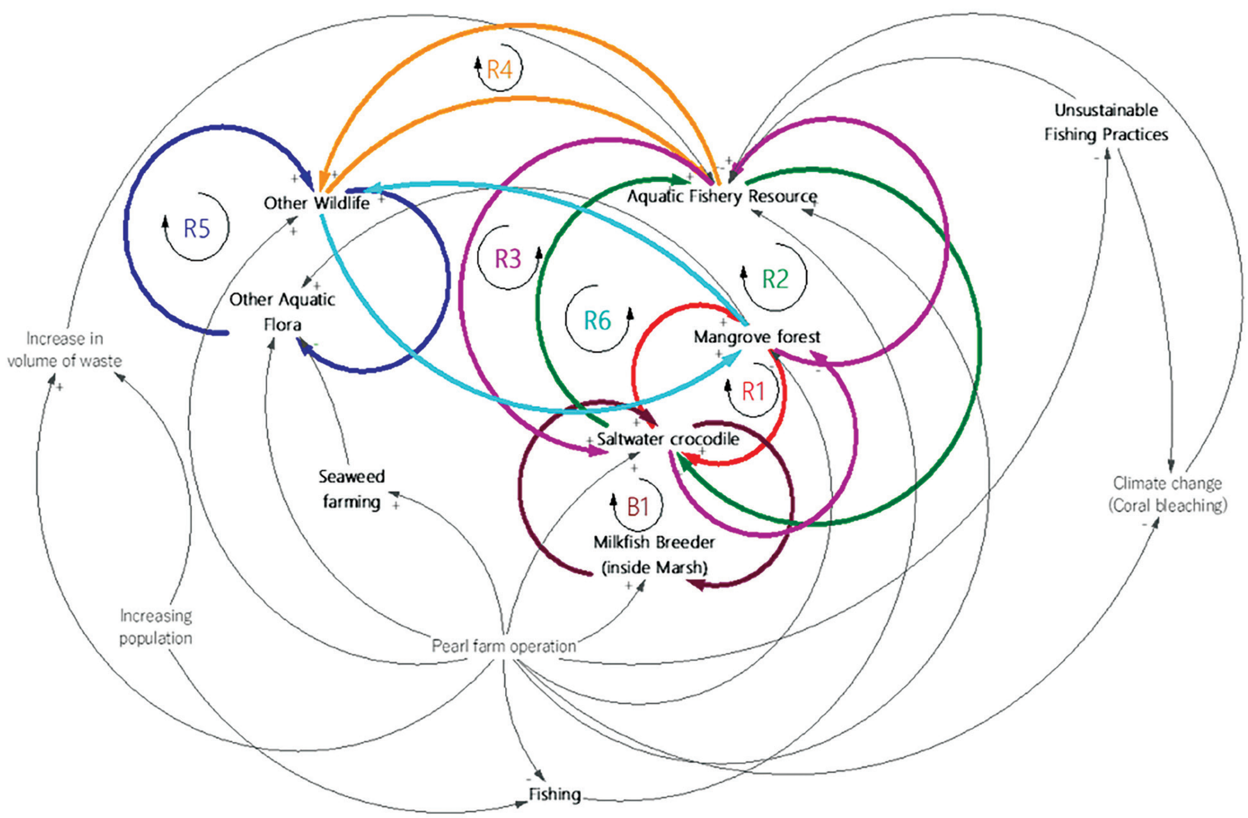

Figure 2. Causal loop diagram (CLD) of the mangrove-crocodile-fishery for Bugsuk Island based on the two FGDs.

strict management of the protection zone becomes the determining factor in ensuring the conservation of resources, guaranteeing their continued existence. The community learned to live with it and, thus, respect the resources including the saltwater crocodiles, bringing fear from the neighboring areas. The locals realized the importance of the continued existence of these resources to ensure the sustainability of the supply of marine harvest that they currently enjoy.

DISCUSSION

Reinforcing Loop 1: Mangrove Forests and Saltwater Crocodile Interaction

Mangrove forests provide food and shelter for saltwater crocodiles and nurseries for fishery resources. Mangrove-associated fauna such as fish, snakes, rodents, bats, and monkeys also serve as food for the saltwater crocodile. Similarly, the presence of crocodiles in the coastal mangroves and estuarine ecosystem somehow deters local residences from engaging in fishing. The interaction of mangroves and crocodiles on the island is a continually growing system and exhibits both positive polarities. Positive polarities of both variables indicate growth. Although the loop vaguely illustrates the role of saltwater crocodiles as nutrient recyclers, the mangrove forest continues to expand in the area, and the population of saltwater crocodiles also increases in the same direction.

It is, however, acknowledged that latent loops can manifest in the future transforming reinforcing loop into a balancing loop. This stage ensures that the crocodile and mangrove populations can be constrained by other factors preventing exponential growth. Intrinsic biotic and abiotic factors interact to stabilize the environment (Chapman and Byron 2018).

Reinforcing Loop 2: Aquatic Fishery Resources and Saltwater Crocodile Interaction

Aquatic fishery resources include all other fishery resources that are found in the marine environment of Bugsuk Island – including demersal and pelagic fishes, shellfishes, invertebrates, and crustaceans. These resources exhibited a reinforcing growth with the saltwater crocodile. The presence of crocodiles in the marine estuaries contributes to increasing available food sources for the fisheries. This interaction is somehow related to the findings of Bucol *et al.* (2020), who attributed the increased fish catch to various factors, particularly the low fishing pressure that discouraged local fishermen from intensive fishing. Somaweera *et al.* (2020) also suggested that crocodiles have very little influence on the nutrient levels in the water and, consequently, on aquatic productivity. But this minimal benefitting relationship would also develop and strengthen over time. Thus, positive polarities of variables indicate the continuing growth of each variable along with the growth of the other moving toward the same direction.

The FGD resulted in a reinforcing loop, but there were balancing loops in place to stabilize the population. Fishing activities and food sources by crocodiles help balance the fishery resources. Additionally, reaching carrying capacity may suppress population growth, serving as a balancing effect for both the fishery resources and the crocodile population.

Reinforcing Loop 3: Aquatic Fishery, Mangrove Forests, and Saltwater Crocodile

This loop showed that mangrove forests support fisheries by providing shelter and food for marine life. The decomposing organic matter in mangrove areas is vital to the aquatic food chain (Hutchison *et al.* 2014), sustaining the fishery resources on the island. Additionally, the presence of saltwater crocodiles further contributes to the available food sources, deterring illegal activities and benefiting both the fisheries and the habitat. These three elements support each other, leading to mutual growth.

Reinforcing Loop 4: Other Wildlife and Aquatic Fishery Resources

The island is home to a variety of wildlife, including terrestrial wildlife species living within the mangrove forests and marine life like rays, whales, and dolphins – as identified in FGD. Most of this wildlife relies on the available fish supply for their sustenance and growth. The local island resources, particularly the aquatic fishery resources, have a growing relationship with the wildlife. The wildlife on the island depends on the abundant food sources from the marine areas, and even monkeys have been observed collecting shellfish for food. This growing relationship is shown through positive interactions, and the continuous presence of both resources helps to sustain each other. Additionally, there will be a balancing loop to stabilize the interaction and prevent the system components from increasing indefinitely.

Reinforcing Loop 5: Other Wildlife and Other Aquatic Flora

Other aquatic flora – including seagrasses, seaweeds, *Pandanus* species, orchids, and *Nypa* – unequivocally support fisheries. Seagrass and seaweed beds are vital habitats for numerous species, including threatened marine turtles (Fortes 2012). The grazing activity of turtles undeniably enhances the structure and above-ground biomass of the beds (Aragones and Marsh 2000). This relationship demonstrates a positive relationship beneficial for both variables.

Reinforcing Loop 6: Other Wildlife and Mangrove Forest

The mangrove forests in Bugsuk Island definitely support a diverse array of wildlife. The lush vegetation provides shelter and food for various animals such as snakes, birds, fireflies, bees, otters, monitor lizards, and bats. The extensive mangrove canopy and root system serve as a safe refuge for aquatic organisms from predators. Additionally, the feeding and waste discharge patterns of large terrestrial wildlife contribute to soil productivity, providing essential nutrients for forest growth. This symbiotic relationship is clearly demonstrated in the reinforcing loop. However, the density of the wildlife population is ultimately determined by the ecosystem's capacity to sustain its needs. The availability of shelter and food ensures the persistence of the wildlife, but their numbers are balanced based on the area's limitations (Odum 1971).

Balancing Loop 1: Saltwater Crocodile and Milkfish Breeder

In the inland marsh, there is a large population of saltwater crocodiles that require a bountiful supply of food. The available food supply includes ducks, monitor lizards, monkeys, bats, and large mature fish breeders. An adult crocodile consumes about 11% of its weight per week (Bolton 1989). Considering the large population of crocodiles, a substantial amount of food is needed. The crocodiles' feeding action on the milkfish breeders regulates their population. An increase in the crocodile population may lead to a decrease in milkfish breeders, resulting in a negative polarity. However, the high crocodile biomass present in the marsh area serves as nutrient recycling, making food supply available for milkfish and increasing their numbers. The population of milkfish breeders is controlled by the predation action of the saltwater crocodile. The finite area size of the habitat serves as a limiting factor for the biomass growth of the saltwater crocodile, creating a balancing relationship. Both crocodiles and fish breeders are confined to the inland marsh with a defined area for their growth and survival.

CONCLUSION

The interaction between mangroves and crocodiles shows positive growth with both populations expanding. The presence of crocodiles affects human activities serving as a deterrent for resource collection. However, as latent loops develop, reinforcing loops can transform into a balancing loop. This is reflected in the interaction of the fishery resources in the marine environment of Bugsuk Island, wherein reinforcing and balancing loops in the ecosystem are seen to stabilize the population.

Mangrove forests support fisheries by providing shelter and food for marine life, thereby sustaining fishery resources. The presence of saltwater crocodiles further contributes to available food sources, deterring unsustainable fishing practices and benefiting both the fisheries and the habitat. Other wildlife on the island depends on the abundant food sources from the marine areas, and there are positive interactions showing a continuous presence of both resources helping to sustain each other. Aquatic flora serves as an important habitat for various aquatic wildlife species demonstrating a mutually beneficial relationship. A balancing loop to stabilize the interaction between aquatic wildlife and habitat prevents the system components from increasing indefinitely. The wildlife population, however, is ultimately determined by the ecosystem's capacity to sustain its needs.

The contributions of mangrove forests, aquatic fisheries, and saltwater crocodiles are important and interconnected, influencing and regulating growth. Bugsuk Island represents a unique diversity with great potential for resource conservation and economic benefit.

ACKNOWLEDGMENTS

The author wishes to thank the institutional support from the Crocodylus Porosus Philippines Inc. through the Charles Andy Ross Crocodile Conservation Research Fund, Palawan Wildlife Rescue and Conservation Center, Palawan Council for Sustainable Development Staff, Jewelmer International Corporation, and the Capturing Coral Reef Ecosystem Services Project. The technical participation of Benjamin D. Adriano Jr., Amelyn S. Dramayo, Meljory D. Corvera, Jake Wilson B. Binaday, Salvador L. Guion, and William L. Tabinas in data collection.

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