Assisting Mangrove Reforestation Outreach through the Development of Educational Tools

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LimPiaR
Corporación Piñones Se Integra (COPI)

Figure 1. Kayaking through the Clemente Canal

Photos Courtesy of Roberto Lopez, Marcos Peñaloza, Shawn Escalera, Nuria Esclera, Paola Rodon Diez, COPI website, Professor Robert Hersh, Angel A. Berudez Gagot, Rachael Swanson Geneva Isaacson, and Gianluca Panza

Figure 2. Sign Posted at the Peninsula of the Fishermen

Abstract

Mangroves provide important ecosystem services such as habitats, shoreline stabilization, and protection of coastal communities from tidal surges and natural disasters. Over the past 50 years, more than 25% of the world's mangroves worldwide have been lost due to natural disasters, pollution, and urban development. The Piñones area in Puerto Rico hosts 22% of all mangrove forests on the island. Our team worked with La Corporación Piñones Se Integra (COPI) on their Community-Based Mangrove Management (CBMM) reforestation program to understand the importance of mangroves and the threats they face. We also worked with LimPiaR to develop four participatory games and a mangrove wave tank as part of an Environmental Learning Outside of the Classroom (ELOC) educational portfolio.

Acknowledgements

Our team was fortunate to work with many people who helped drive our group to become more involved, think deeper, and make meaningful connections. Thank you to La Corporación Piñones Se Integra (COPI) and Maricruz Rivera Clemente, Marcos Peñaloza and the reforestation team at COPI for allowing us to work with them and providing us insights into the importance of mangroves in the area.

Our co-sponsor Auraluz Guzman from LimPiaR provided extensive guidance in Environmental Learning Outside of the Classroom (ELOC) and assistance in creating our participatory games. Thank you to Paola Rolon Diaz, Angel A. Berudez Gagot, and Shawn Escalera for being wonderful co-researchers and friends. Thanks to Jami Claypoole for her extreme hospitality. We also acknowledge Nuria Escalera for her insights into the history and context of Piñones and the community's relationship to their mangroves.

We would also like to acknowledge our advisors Professor Robert Hersh and Professor Leslie Dodson for their guidance and mentorship. We are extremely grateful for their time and energy.

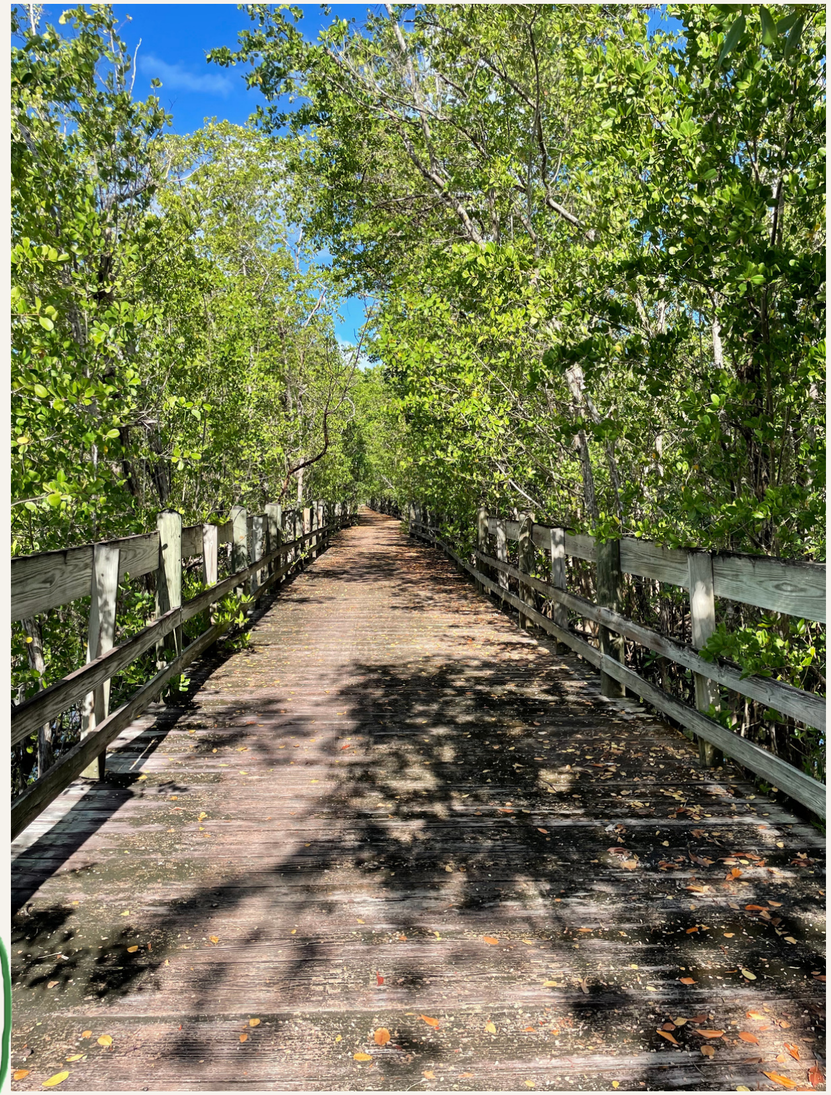

Figure 3. Piñones Boardwalk

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Executive Summary	Panza	N/A	All
Introduction	All	N/A	All

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Benefits of Mangroves	McKnight, Panza	Issacson	All
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Mangrove Juggle	Issacson	Panza, Issacson	Panza
7 Day Mangrove	McKnight	Mcknight	Issacson
Unstable Mangroves	Issacson	Issacson	All

Findings			
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Participatory Tools Can be Effective Tools to Educate Community Members About the Importance of Mangroves	All	N/A	All

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Reccomendations	Issacson	McKnight	Panza
Ethics	Panza	N/A	Issacson
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Concluding Remarks	All	N/A	All

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Executive Summary

Mangroves serve as important ecosystems for thousands of species. They protect coastal communities from natural disasters, sequester massive amounts of carbon dioxide, improve water quality, and support a variety of economies. Despite the importance of mangroves worldwide, they have seen a global decline due to human activity and natural disasters. In Puerto Rico, dual 2017 hurricanes Irma and Maria devastated the island of Puerto Rico and destroyed more than half of the mangroves on the island (FEMA, 2018). Natural recovery of mangroves can take as long as 30 years or more (Branoff et al., 2019; Ferwerda, Ketner, & McGuinness, 2007), making mangrove maintenance and reforestation efforts vital. The Piñones community on the north coast of Puerto Rico hosts the largest mangrove forest on the island representing 22% of the island's mangroves (Ruiz, 1999).

Figure 4. Kayaking Down the Clemente Canal

Goals and Objectives

The goal of this project was to utilize local knowledge and expertise about mangrove maintenance and educational games to develop participatory games and a wave tank simulation demonstrating the importance of mangroves in Piñones to assist mangrove reforestation outreach.

We came up with four objectives to meet this goal:

1. Identifying community priorities in mangrove restoration in context to the Piñones community.

2. Understand the motivation and process of the mangrove reforestation initiative at COPI.

3. Increase community engagement through development of environmental games and activities for the Piñones community.

4. Assess the feasibility of designing and constructing an interactive exhibition for COPI that alerted people to the benefits of mangroves

Our Sponsors

La Corporación Piñones Se Integra (COPI) is a community-based non-profit organization. COPI was founded in 1999 by Maricruz Rivera Clemente, a social worker and sociologist. In response to Hurricane Maria, COPI started a flood mitigation and canal cleaning project in and around Piñones for the sustained conservation of mangroves, to support local ecosystems and for protection against natural disasters. Phase I of the project involves mangrove restoration and reforestation. Five employees maintain a mangrove nursery, clear debris from canals, plant saplings, and document mangrove growth to support the wellbeing of the largest mangrove forest in Puerto Rico.

LimPiaR, is a non-profit organization created in 2018 as a response to the large amounts of trash found along the coastline of Piñones after hurricane Maria. Spanish for “clean up,” LimPiaR was created to fight pollution through clean-up efforts and by promoting public discussions around recycling and waste management. As part of LimPiaR’s mission to create a “cleaner and greener” Puerto Rico, they are focused on providing robust environmental education. A leader and educator at LimPiaR, Auraluz Guzman, is currently working towards raising environmental awareness through the implementation of environmental games with young children in Piñones.

Key Informant Interviews

Key informant interviews, used to gain expert information on specific topics, provided our team with necessary background on COPI's mangrove management initiative. Additionally, they supported the design and development of our participatory games and simulatory wave tank. We conducted a total of four key informant interviews with Marcos Peñaloza, Maricruz Rivera Clemente, Nuria Escalera, and Auraluz Guzman.

Figure 5. Red mangrove saplings ready to be planted

Participatory Research

Participatory research was used to gain experience and information on the specifics behind mangrove reforestation and to form an understanding of mangrove management. Our team worked with the COPI reforestation team and engaged in field research to learn more about the mangrove forest, the reforestation process, and the importance of management. Our field research consisted of visiting three different mangrove reforestation zones around Piñones to plant, document, and observe mangroves there. We worked in the Clemente Canal, the Piñones Boardwalk, and the Peninsula of the Fishermen.

In all these locations, our team helped plant red mangroves to protect the coastline. During this immersive field work, we learned about, and participated in, the planting processes for different zones and mangroves. We assisted in identifying zones based on observing sections of canals or coastlines that had seen a noticeable decrease in the health of the mangroves or ecosystem. The zones were marked off and reforestation efforts were done considering suitable mangroves for the area.

Developing and evaluating participatory games and an educational wave tank

We prototyped, developed, tested, and evaluated four participatory games to educate players about the importance of mangrove reforestation, the threats to mangroves, and the ecology of the mangrove forests specific to Piñones. We developed game prototypes with the help of our sponsors and advisors based on information we learned about mangroves during our work in the reforestation zones and through key-informant interviews. The method that we choose to develop, test, and evaluate our games was based on the Climate Centre's development process, and the e-VITA development process and evaluation frameworks.

Additionally, we designed and built a four-foot-long educational wave tank to serve as a physical exhibit in COPI. This exhibit serves as an interactive way to demonstrate the importance of mangroves in protecting coastal communities from flooding. Through our conversations with Marcos and initial testing of different designs, we came up with a final design that we were able to build and display at COPI.

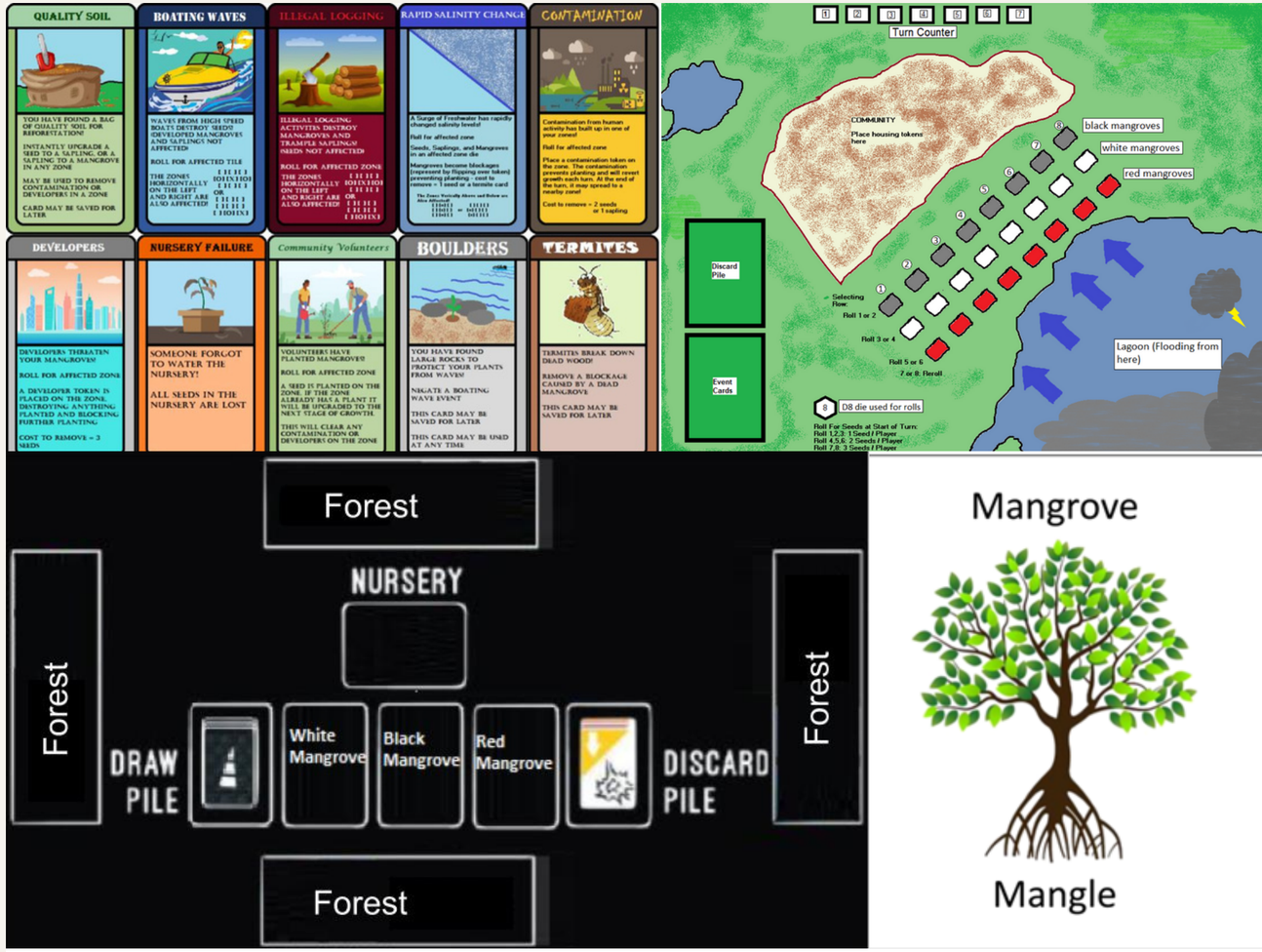

Figure 6. Collage of Game and Tank Design and Components

Findings

Through our interviews with local stakeholders and conducting of field research, we found that the mangrove forest in Piñones serves the community in a variety of way and face several threats specific to the community. Understanding issues specific to Piñones through field research and key informant interviews informed the creation of informal educational materials and learning outcomes for the Piñones community. The four participatory games that we prototyped, developed, and tested ranged in success for achieving their intended learning outcomes while engaging and stimulating the interest of the participants. Notes, observations, and debrief questions informed iterations of each of our games in order to improve user experience, game engagement, and learning outcomes. Additionally, we successfully designed and constructed a stimulatory wave tank exhibit held at COPI with the purpose of catching the attention of visitors and raising awareness for the importance of mangroves in Piñones.

Figure 7. Collage of Deliverables being tested

Limitations

Our primary limitation was time. We found that we needed more time than we had expected to develop, prototype, test, and iterate on four participatory games and a wave tank. The games would benefit from further testing. Additionally, the creation of the simulation wave tank took longer than expected, largely due to difficulty acquiring materials. Due to limitations with materials and build time, we only able to fully build the tank and its components along with a poster about the tank. We did not have anyone other than our sponsors and our team interact with the tank.

We also struggled with the language barrier. One of our co-sponsors, Marcos Peñaloza at COPI, only spoke Spanish and understood some English. Some of our team understood a little Spanish, but not enough to understand important scientific and cultural information. As one of our key informants, Marcos held the expertise on mangrove reforestation. Fortunately, we had the help of our co-researchers and other key informants to assist in the translation process. Fortunately, Marcos is an extraordinarily patient person and an exceptional educator. We learned a great deal from him even though we did not share a common language.

Figure 8. A red mangrove sapling reaching towards the sky

Recommendations

1. Continue testing, evaluating, and iterating the participatory games.

2. Test and refine the simulation wave tank.

3. Host environmental education nights with COPI and LimPiaR to facilitate the use and further testing of the participatory games and wave tank.

4. Continue to make environmental educational material, directed at different target audiences with more learning outcomes.

Figure 9. Our team's recommendations moving forward

Chapter 1: Introduction

Figure 10. Nursery at COPI

Introduction

Mangroves are a type of saltwater tree that grows along coasts in tropical and sub-tropical areas (Goldberg et al., 2015). Mangrove forests provide a host of benefits to coastal communities, primarily by reducing soil erosion, providing a habitat for thousands of species, reducing the impact of natural disasters, and by sequestering carbon to combat global warming (Schmitt & Duke, 2015). Over the last 50 years, there has been a global decline in mangrove populations with 20%–35% lost worldwide (Goldberg et al., 2015). These losses were dominated by clearings for coastal land development, urbanization, overexploitation for natural resources such as timber, and the effects of climate change (Goldberg et al., 2015).

A combination of manmade and natural causes has led to a sharp decline in the acreage of mangroves in Puerto Rico. Between 1800-2008, mangrove forests in Puerto Rico have decreased by nearly 30% to 8,323 hectares, largely due to agricultural practices and more recent urbanization (Martinuzzi et al., 2009). Tropical storms also pose serious threats to the health of mangroves across the island.

According to a study conducted by the Federal Emergency Management Agency (FEMA), Puerto Rico suffered an average mangrove mortality of 53% a year after the twin 2017 hurricanes Irma and Maria (Brandoff et al., 2018). Damage included defoliation, uprooting of trees, and breaking of tree branches or trunks. The destruction to the forests catalyzed community efforts to restore and clear the mangroves of debris (Brandoff et al., 2018).

While mangroves naturally recover slowly over time, it is essential to maintain them in coastal communities such as Piñones, where 22% of Puerto Rico's mangroves are located (Ruiz, 1999). These communities are vulnerable to the effects of storm surges and flooding from hurricanes; however, healthy coastal mangrove forests may reduce the height of storm waves by 13%-66% per 100m of mangroves (Spalding et al., 2014). Regular maintenance and reforestation efforts can have a positive effect on the health of mangroves and surrounding communities (Peñaloza, 2021). Traditionally, fishing and crabbing communities in Piñones would maintain

Figure 11. A 20,000 square foot section of mangroves in Piñones, Puerto Rico was submerged during Hurricane Maria in 2017. The grove had not recovered four years later

and restore the mangrove forests by removing debris and blockages from canals to use as charcoal feedstock and firewood. In 1972, Puerto Rico's Department of Natural and Environmental Resources was founded and enacted environmental regulations to protect mangroves by restricting fishing, crabbing, and the removal of mangrove wood (DRNA, 2015). Those restrictions, however, had the unintended effect of limiting the economic incentives for the community to manage their mangroves. In order to enhance community-based mangrove management in Piñones, La Corporación Piñones Se Integra (COPI), a non-governmental organization launched a community initiative to restore and protect Puerto Rico's largest mangrove forest. COPI is a community-based non-profit organization in Piñones committed to preserving local culture and working to address social, economic, and environmental issues in the community. Since July 2021, five full-time employees of COPI have embarked on a reforestation initiative to maintain and restore the mangroves in Piñones, with the goal of protecting the community in case of future natural disasters. COPI is a co-sponsor of this project along with LimPiaR. LimPiaR is a non-profit organization with the mission of achieving a cleaner and greener Puerto Rico while also providing educational information geared toward raising environmental awareness.

Our project is to utilize local knowledge and expertise about mangrove maintenance and reforestation to create a portfolio of participatory educational games and a simulated wave tank that can be used by co-sponsors and others interested in Environmental Learning Outside of the Classroom.

Figure 12. Young red mangrove at the Peninsula of the Fishermen

Chapter 2: Background

1

Properties and Importance of Mangrove

2

Mangroves in Puerto Rico

3

Community Based Mangrove Management and Educational Outreach

Background

Below, we discuss the importance of and threats facing the mangrove forest in Piñones, a small coastal community in Puerto Rico. We provide an overview of mangrove ecology, the global importance of mangroves, and the threats to mangroves from climate change. We also explain Puerto Rico's mangrove forests, including our co-sponsor COPI's mangrove reforestation program and the co-sponsor LimPiaR's involvement in environmental education initiatives. We review the best practices for Community-Based Management of Mangroves (CBMM) and investigate theories of Environmental Learning Outside of the Classroom (ELOC) in the context of community involvement and environmental educational related to the mangrove forests in Piñones-- reforestation programs and outreach.

The Piñones Mangrove Forest

The largest Puerto Rican mangrove forest, representing 22% of the island's mangroves, is found in the Piñones community (Ruiz, 1999). Piñones is part of the Loiza municipality, the center of Puerto Rico's Afro-Caribbean culture. During Spanish colonial rule, slaves purchased their freedom and began to form settlements, one of which would later become the town of Loiza (Santiago, 2007). As settlements developed, residents established important economic relationships with the mangroves around them. Dating back to the 1870s, Piñones residents utilized wood from the mangrove forest for lumber, firewood, and charcoal production (Cordero, 1970). This traditional usage continued into the 1950s when firewood and charcoal making gained increased economic importance.

Today, the Piñones mangrove forest continues to serve the community in a variety of ways. The mangrove forest "controls floods, reduces erosion, serves as a fish spawning area, and shelters a wide variety of species" (Ruiz, 1999). In the Piñones forest, approximately 70% of existing flora are mangroves. These mangroves serve as important ecosystems for birds, fish, mollusks, and crustaceans and are home to approximately 96 species of birds and 38 species of fish, including some that are designated as endangered such as the brown pelican and leatherback turtle (Peñaloza, 2021). Mangrove forests also have a scenic and cultural value for the community, supporting ecotourism and the local economy.

Figure 13. A 30-year-old tree in the Clemente Canal. Extensive tree roots once connected both banks of the canal. The enormity of the tree created a blockage that impeded boats, natural current flow, and animals. COPI cut the tree to clear the canal as an escape route in the event of a natural disaster

Changes in Mangrove Covers in Piñones

Over the past 200 years, mangrove forests in Puerto Rico have experienced drastic changes, largely due to human factors. The most significant stress on mangroves has been agricultural and urban development through the 19th and 20th century. Between 1800-1938, mangrove cover in Puerto Rico was reduced by as much as 45% (Martinuzzi et al., 2009). During that time, a shift in Puerto Rico to an agricultural economy contributed to a major decrease in mangroves across the island. Forests were extensively transformed into agricultural fields through deforestation and drainage (Martinuzzi et al., 2009).

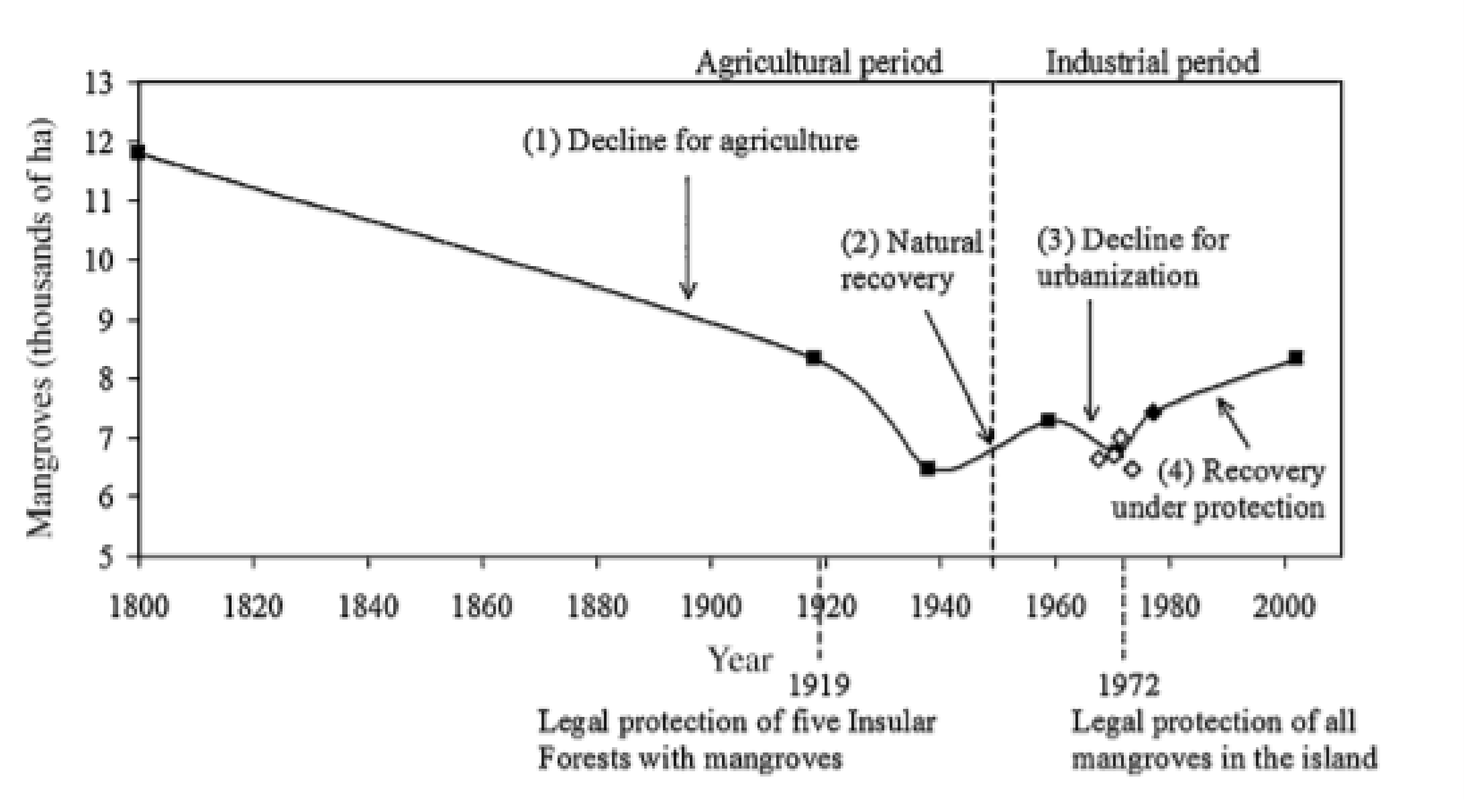

Figure 14. Changes in mangrove forest cover in Puerto Rico over the last 200 years (Martinuzzi et al. 2009).

Near the end of the agricultural period, mangroves began to recover naturally, as Puerto Ricans began to move into urban centers and abandoned agricultural lands (Martinuzzi et al. 2009). Additionally, some reforestation efforts were made in protected areas, helping mangrove cover increase by 12% between 1938-1959 (Martinuzzi et al., 2009). This period of growth in mangrove cover, however, was followed by rapid urbanization of coastal lands that led to another steep decline in mangrove as housing developments and other infrastructure destroyed mangrove forests. That to make way for housing developments and other infrastructure, a decline that continued until 1972, when legal protections were placed on all mangroves in Puerto Rico (Martinuzzi et al., 2009) (Figure 14).

Environmental Legislation and Protection

Puerto Rico's 1972 Ley Orgánica del Departamento de Recursos Naturales (1972, 20 June) set aside provisions to create the Departamento de Recursos Naturales, or DRNA, to protect the environment. One of the natural resources to be protected was mangrove forests and regulations banned the use or clearing of the forests (DRNA, 2015). More recently, as a result of conservation goals for states and territories set by the 2008 Farm bill, the Puerto Rico Forest Action Plan was created, which defined the mangrove forests of Piñones as one of several "critical wildlife areas," or CWA's (DRNA,2015). That designation prohibits land development in wetlands, along with other protections (DRNA, 2015). The intent of the protections is to prevent the exploitation and damage of critical wildlife areas. However, for many Piñones community members, mangrove protections halted practices that traditionally preserved and maintained the health of the mangroves such as fishing, crabbing, and removing debris, fallen logs, or excess dead trees for charcoal (N. Escalera, personal communication, October 28, 2021). Some community members say that mangrove protections removed the economic incentive for the community to manage and maintain the canals and mangroves in Piñones (N. Escalera, personal communication, October 28, 2021).

Development of Piñones

Despite legislative and regulatory protection of mangroves, urban expansion and coastal development continue to pose serious threats to the Piñones mangrove forests. In the decade between 1960-1970, developers tried several times to build resorts in the mangrove forest of Piñones but were turned back by stiff opposition from environmentalists and community residents (Martinuzzi, 2008). Additionally, contamination from septic tanks, tourism, and boating threaten the health of the Piñones mangroves. Extensive tourism and a Yacht Club directly across from the community's main lagoon also put pressure on the Piñones forest (Peñaloza, 2021).

Mangrove Biology

The term "mangrove" refers to any woody plant that grows in the intertidal zone characterized by regular tidal flooding, and brackish water intermediate in salinity between salt and fresh water (Tomlinson, 2016). This definition includes 110 species of mangroves; however, most experts acknowledge 54 "true mangrove" species that grow almost exclusively in traditional mangrove habitats such as lagoons, estuaries, and saline swamps (Tomlinson, 2016).

There are four mangrove species in Puerto Rico: the red mangrove (Rhizophora mangle), white mangrove (Laguncularia racemosa), black mangrove (Avicennia germinans), and buttonwood mangrove (Conocarpus erectus) (DRNA, 2016). Red mangroves are found closest to saltwater coasts, while buttonwoods are found furthest inland (Figure 15). In the Caribbean, only the red, black, and white mangroves are considered by Tomlinson to be true mangroves. The buttonwood mangrove is not considered to be a "true" mangrove as it grows farther inland than most mangroves and is therefore not exclusive to the intertidal zone (Tomlinson, 2016).

The intertidal zone is a harsh environment of high salinity (salt content) that few plants can tolerate (Flowers & Colmer, 2015). Mangroves belong to a classification of plants known as halophytes that are characterized by their ability to thrive in these salty conditions (Flowers & Colmer, 2015). Flowers and Colmer (2015) note that halophytes possess unique adaptations that allow them to tolerate high salt conditions as salt needs to be removed, excluded, or otherwise managed to avoid lethal salt buildup in plant tissues. For example, the red mangrove regulates salt levels through adaptations to their root structure that significantly reduces the passage of salt into the plant (Duke & Allen, 2006).

Intertidal zones are also home to saltwater swamps characterized by low oxygen levels that require special adaptations by mangroves (Ellison et al., 2015). For example, black mangroves utilize straw-like protrusions called pneumatophores that act as breathing tubes for the plant to intake more oxygen (Ellison et al., 2015). Providing the characteristic look of black mangrove forests, they appear as many short vertical roots that emerge from the soil around each tree. Finally, the flow of current is critical to mangrove health as the trees rely on the changing tides to wash excess salt from the plants, remove waste, distribute seeds, and bring in nutrients (Booker et al., 1998).

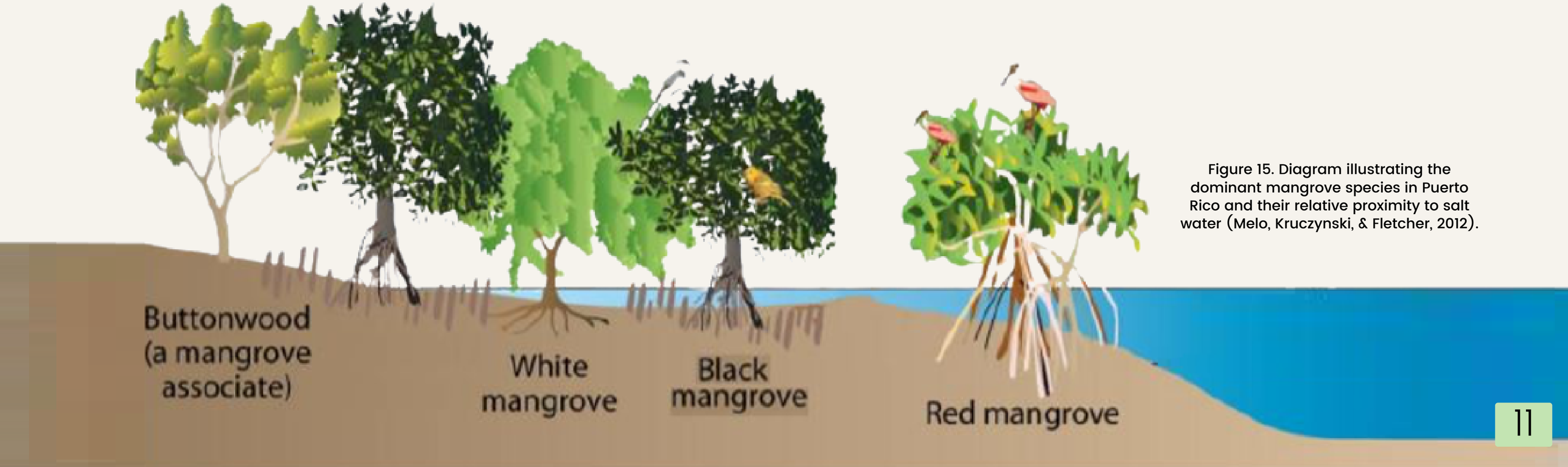

Figure 15. Diagram illustrating the dominant mangrove species in Puerto Rico and their relative proximity to salt water (Melo, Kruczynski, & Fletcher, 2012).

Benefits of Mangroves

The Mangrove Ecosystem

According to the U.S. Fish and Wildlife Service, mangrove ecosystems are an important habitat for a wide variety of animals, with many mammals, birds, reptiles, fish, and amphibians dependent on mangroves for shelter, breeding, nesting, and foraging. Fish rely on the calm waters and pools found in mangroves for spawning. Other frequent visitors include migratory birds that travel to the ecologically active mangroves during winter periods (U.S. Fish and Wildlife Service, 1999). Termites are a particularly important species in the mangrove ecosystem; by feeding on fallen dead wood, they help break it down back to accessible soil (Vane et al., 2014) (Figure 16). Animal droppings and other material derived from the organisms that inhabit the mangroves also provide organic inputs into the ecosystem (Vane et al., 2014).

Figure 16. Termite nest in Clemente Canal

Erosion and Tidal Surge Protection

Mangroves protect the land around them from erosion and tidal surges. A policy guide by Wetlands International and The Nature Conservancy found that hundreds of meters of mangroves can mitigate most coastal damage, and that wave height is reduced by 13%-66% per 100m of mangroves (Spalding et al., 2014). While they acknowledge tsunamis will overwhelm mangroves, a deep mangrove forest is still capable of reducing tsunami flood depth by 5%-30%. In the context of erosion, deep mangrove forests break up wave energy and encourage sediment collection, which balances soil erosion from waves and tides (Spalding et al., 2014). The same properties that lend mangroves to protect against erosion also results in their role in water filtration. Kathiresan (2003) notes the effects of mangroves on filtration of sediments: the water current slows as it flows through a mangrove in a process that encourages fine sediment and debris to settle into the soil (Kathiresan, 2003). This clarifies the water and improves the health of organisms which inhabit it.

Mangroves Benefit Communities

Humans derive several benefits from the vast ecosystem of mangrove forests. These forests provide resources such as timber, fuel, and charcoal feedstock as well as areas for fishing and crabbing (UNEP, 2014). According to a report by the United Nations Environment Program, “these ecosystem services are worth an estimated US$ 33,000-57,000 per hectare per year to the economies of developing countries with mangroves” (UNEP, 2014) (Figure 17).

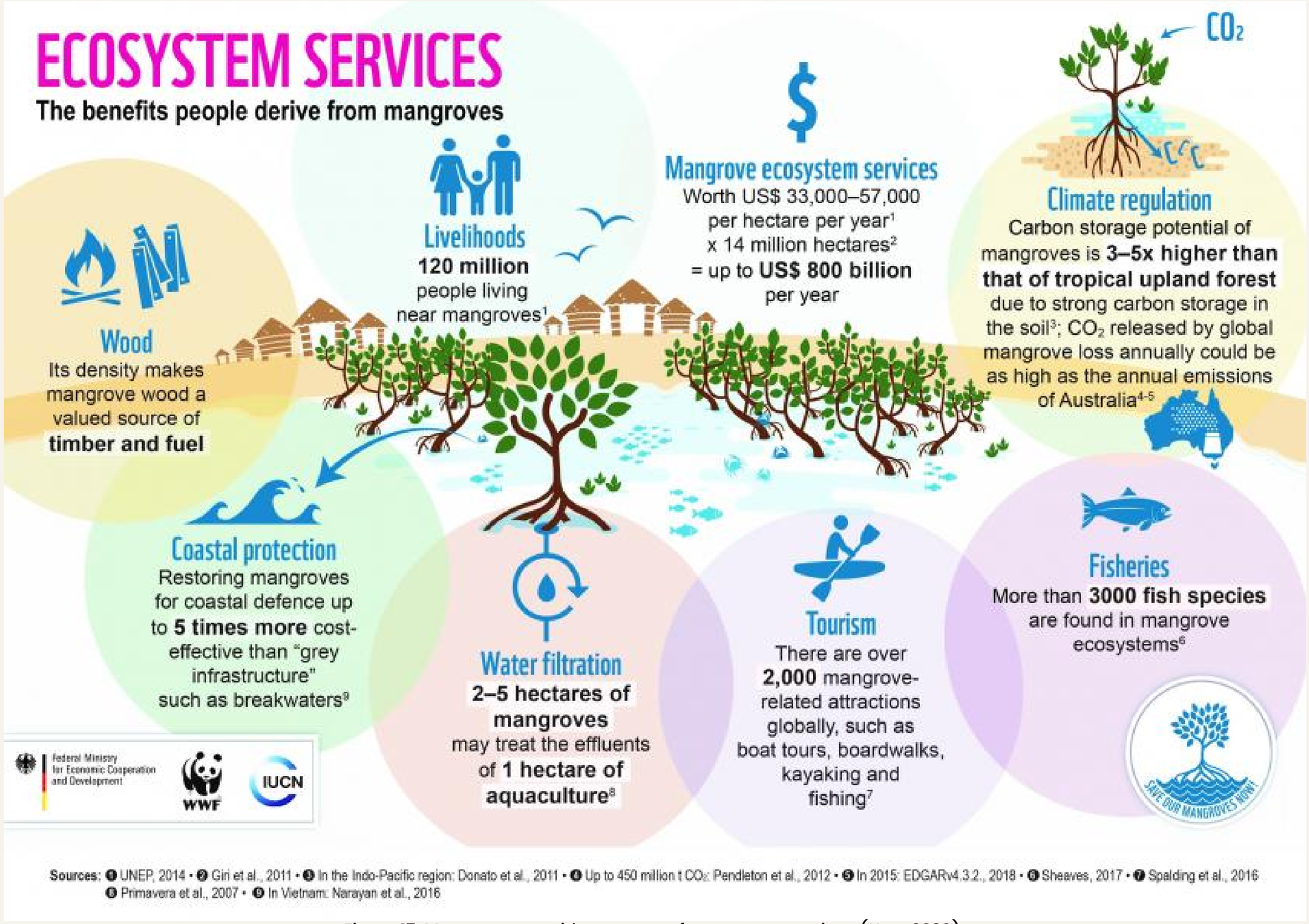

Figure 17. Mangroves provide an array of ecosystem services (Herr, 2020)

Mangrove Ecosystems and Carbon Sequestration

In the context of climate change, the impressive ability of mangroves to sequester carbon highlights their importance as a crucial ecosystem. According to a 2012 review by Daniel M. Alongi from the Australian Institute of Marine Science, from the global perspective of climate change, mangroves are one of the most productive ecosystems. Mangrove ecosystems stores approximately 937 tons of carbon per hectare, placing them among the most carbon rich forests in the world, with more than double the average amount of carbon sequestered compared to broad forest averages (Alongi, 2012) (Figure 18). Note that mangroves store the majority of carbon below ground. Alongi (2012) explains that mangroves store vast amounts of carbon in their root systems, especially in dead roots which act as carbon stockpiles to support the growth of new mangroves.

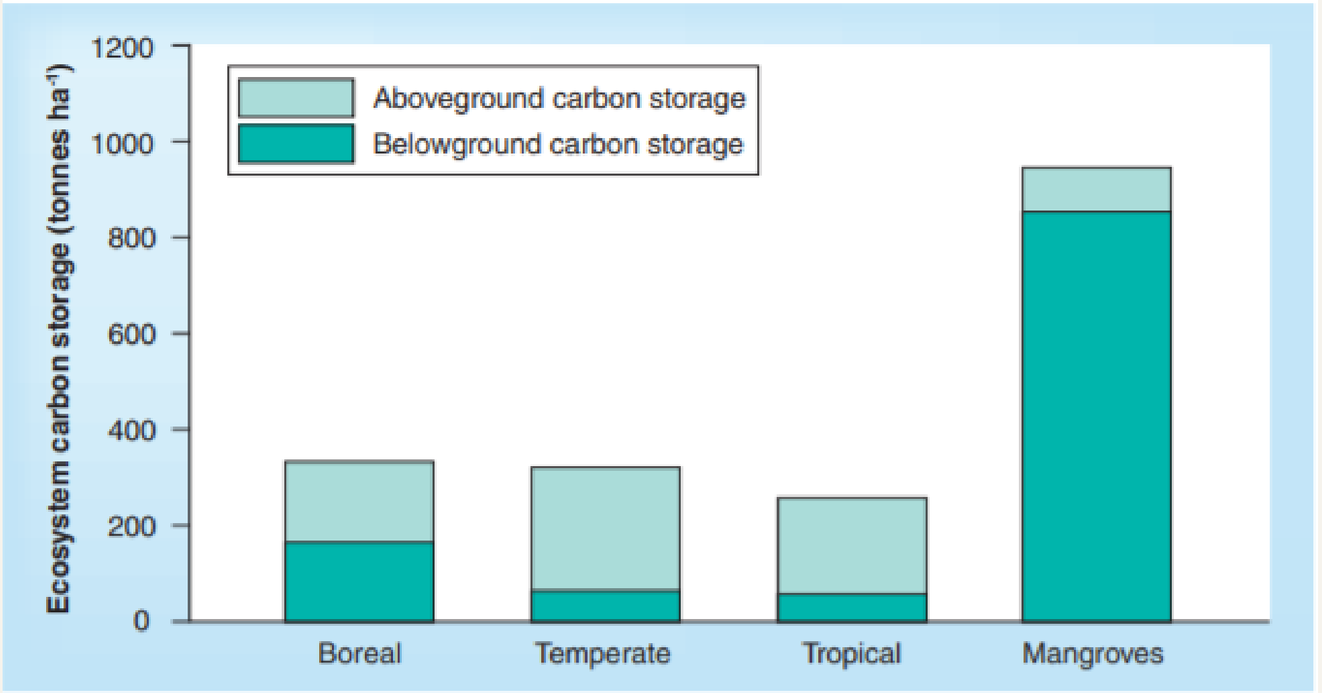

Figure 18. Differences in whole-ecosystem carbon storage among boreal, temperate, tropical forests, and subtropical/tropical mangrove forests (Alongi, 2012)

Threats to Mangroves

Climate Change Mangroves in coastal communities, such as Piñones, face several human and natural threats, chief of which is climate change. The Gilman et al. (2008) review identifies some of the major climate factors affecting mangroves as sea level changes, high water events, extreme weather, precipitation, increased temperatures, and the health of ecosystem components. It is estimated that the sea advances into Piñones at a rate of 0.5-2.3 meters a year (Ruiz, 1999).

Climate Change

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Climate models for Puerto Rico forecast an increase in temperature of 0.02°C per year through 2050 (Climate Change Knowledge Portal, 2021). Rising temperatures are expected to be accompanied by an increase in precipitation and extreme weather events that can be highly destructive (Climate Change Knowledge Portal, 2021). With higher rates of intense storms, mangroves will be damaged more frequently and more severely (Gilman et al., 2008). That was the case in the 2017 hurricane season that buffeted the Caribbean that caused widespread defoliation, tree mortality, uprooting and snapping of trees, variations to food supply and habitats for animals, and modifications to microclimates (DRNA, 2016). A study conducted by the Federal Emergency Management Agency (FEMA) in 2018 found that overall mangrove mortality in Puerto Rico one year after hurricane Maria was 53% (DRNA, 2018) (Figure 19). In some areas of the island, mortality was as high as 98% (Branoff et al., 2019). Natural, unassisted, mangrove recovery is a slow process that can take approximately 30 years or longer (Ferwerda et al., 2007).

In addition to destruction from high winds, large-scale precipitation events are particularly damaging to mangrove forests due to rapid salinity changes which stress the trees (Gilman et al., 2008). Furthermore, as other organisms in the mangrove ecosystem are harmed by climate change, the mangrove forests themselves suffer from lower levels of nutrients and organic material (Gilman et al., 2008).

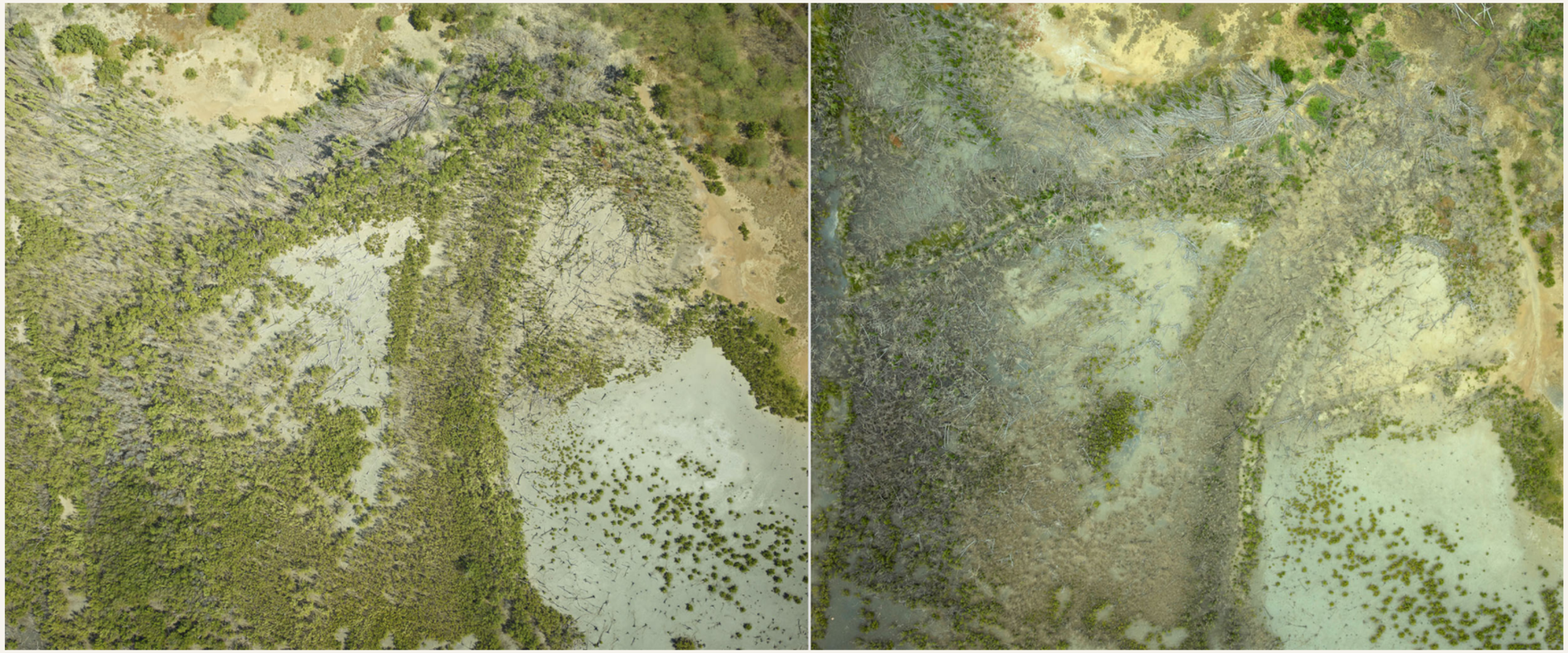


Figure 19. The Jobos Bay mangrove forest in Puerto Rico before (left) and after (right) hurricanes Irma and Maria (Cartier, 2019).

Human Threats to Mangroves

The threats to mangroves from natural disasters are only further compounded by human activity. According to The State of the World's Mangrove Forests: Past, Present, and Future, Friess et al. (2019) state that human-driven deforestation is the most significant source of mangrove loss around the world. They explain that because mangroves provide valuable timber and support ecologically rich ecosystems, many people derive a livelihood from the forests. This can lead to overexploitation of mangrove forests (Figure 20).

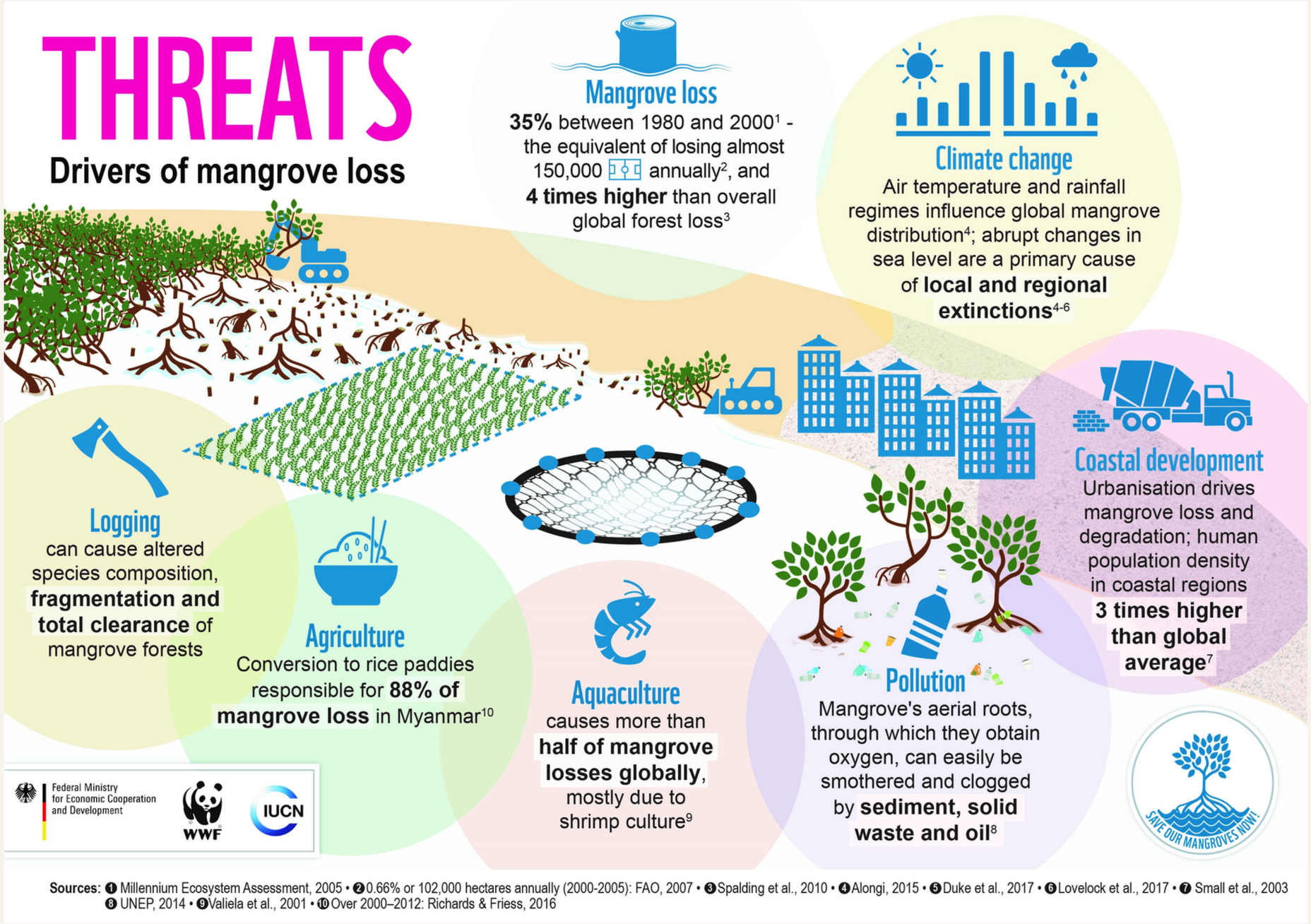


Figure 20. Threats to Mangroves Globally (Herr, 2020)

Other major detriments to mangroves are urban development, pollution, and expansion of agriculture and aquaculture (Friess et al., 2019). Their proximity to coasts means mangroves sit on desirable land for urban development (Friess et al., 2019). Pollution from nearby human habitation through septic systems, trash, and other byproducts also negatively affect the health of neighboring mangroves (Peñaloza, 2021). The expansion of agriculture, particularly for coconuts and rice, is another major driver of mangrove deforestation, along with pollution from fertilizer and other agricultural processes (Friess et al., 2019). Similarly, aquaculture contaminates and pollutes the water around it, which in turn harms neighboring mangrove populations (Friess et al., 2019).

Community Based Management of Mangroves

Due to the importance of mangroves to coastal communities, community organizations are becoming more involved in mangrove conservation. Although mangroves are resilient, forests benefit from reforestation efforts aimed at offsetting the social and ecological pressures on the forest (Martinuzzi, 2008).

Community based mangrove management (CBMM) is an increasingly popular approach to sustainably manage rapidly disappearing mangroves (Walters, 2004). CBMM gives communities the responsibility of managing mangroves in an area by decentralizing rights and responsibilities from government to local communities (Walters, 2004). Numerous studies have found CBMM to be more successful as a forest management strategy than management by the state (Eddy et al., 2016; Kongkeaw et al., 2019). According to researchers from the Marine and Coastal Resources Institute, successful CBMM initiatives include the active involvement and commitment of community leaders and the involvement of community members in mangrove management – from protecting to planting (Kongkeaw et al., 2019). Many CBMM programs share common strategies, including (Kongkeaw et al., 2019):

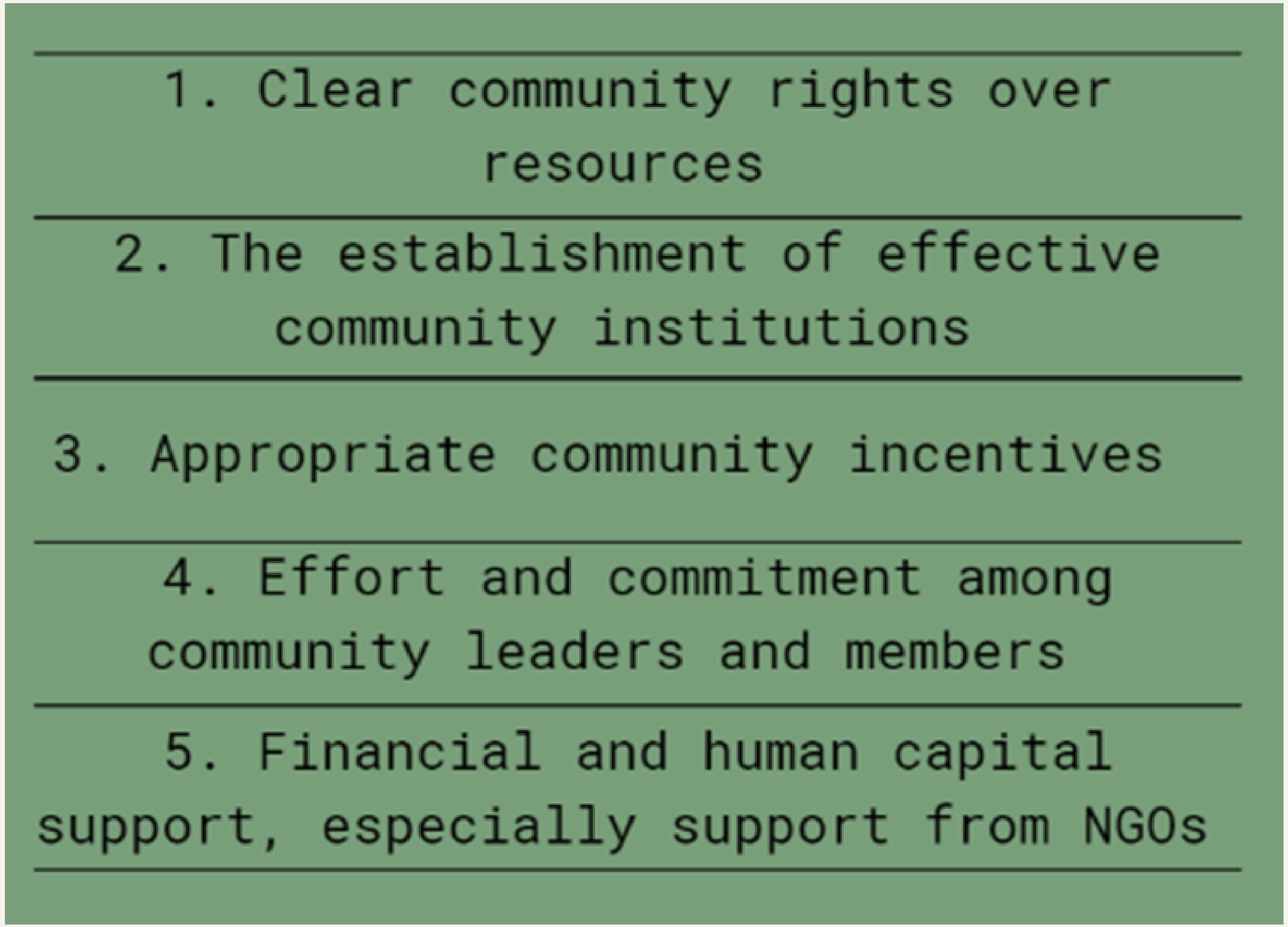


Figure 21. Steps for CBMM(Kongkeaw et al., 2019

CBBM initiatives include community support and support from NGO's and other external organizations. NGO's often provide necessary skills and resources for newly-formed CBMM initiatives, connecting local and scientific knowledge, and communities with different levels of governance. CBMM programs are not independent of government policies, priorities, and mandates, which can either support or constrain CBMM initiatives (Kongkeaw et al., 2019).

Figure 22. WPI team with Marcos Peñaloza and Maricruz Rivera Clemente

Environmental Education

Environmental Learning Outside of the Classroom

CBMM is often accompanied by educational outreach. The combination of community education and peer-to-peer networks encourages community stakeholders to be involved in forest management (Gordon, 2015). Of relevance is Environmental Learning Outside of the Classroom (ELOC). Numerous studies suggest that the best learning resources for environmental education is not only through traditional in-class learning, but also through informal education using interactive media, real-world experience and games (Restu et al., 2017). Learning outside the classroom provides students with experiences that encourage students to "engage a broader range of skills such as teamwork, leadership and compromise in their learning environment" (Stuart, n.d.). Learning outside the classroom can help educators create a learning space to provide a real-world context and expose students to a range of STEM ideas, including environmental science (Berg et al.,2020).

Participatory Environmental Games

An increasingly popular approach to environmental education is through inclusive and participatory games and simulations. A review in the Journal of Universal Computer Science defines an educational game as an instructional strategy that involves competition and is organized by rules and restrictions to achieve certain educational goals (Petri & Gresse von Wangenheim, 2016). According to the International Red Cross/Red Crescent Climate Centre, "participatory games and simulations are effective tools that can approximate the complexity of real life... [while creating] an atmosphere of collaboration and mutual understanding" (Bachofen et al., 2012). Since 2011, the Climate Center has tested a variety of games that promote learning and dialogue, and that elicit insights into climate risk management (Bachofen et al., 2012).

Participatory Game Design

When designing participatory games for environmental education, the Climate Centre suggests following six basis steps (Bachofen et al., 2012):

Participatory Game Evaluation

Many educational games utilize a framework to systematically evaluate games (Petri et al., 2016). While there is no universal standard to evaluate games and gameplay due to the variety of desired learning outcomes and gameplay choices, evaluation frameworks identify factors relevant to gameplay, user experience, as well as factors such as learning objectives, challenge, social interaction, and other desired metrics (Petri et al., 2016). The purpose of this evaluation is to measure the success of an instructional game in meeting defined factors, which allows for revisions to be made for improvement (Petri et al., 2016). Repeating evaluations and revisions allows for the continuous evolution of a game to optimize its ability to deliver learning objectives while possessing refined gameplay (Pappa & Pannese, 2010). In Piñones, both COPI and LimPiaR are organizations which utilize educational programs to reinforce environmental awareness.

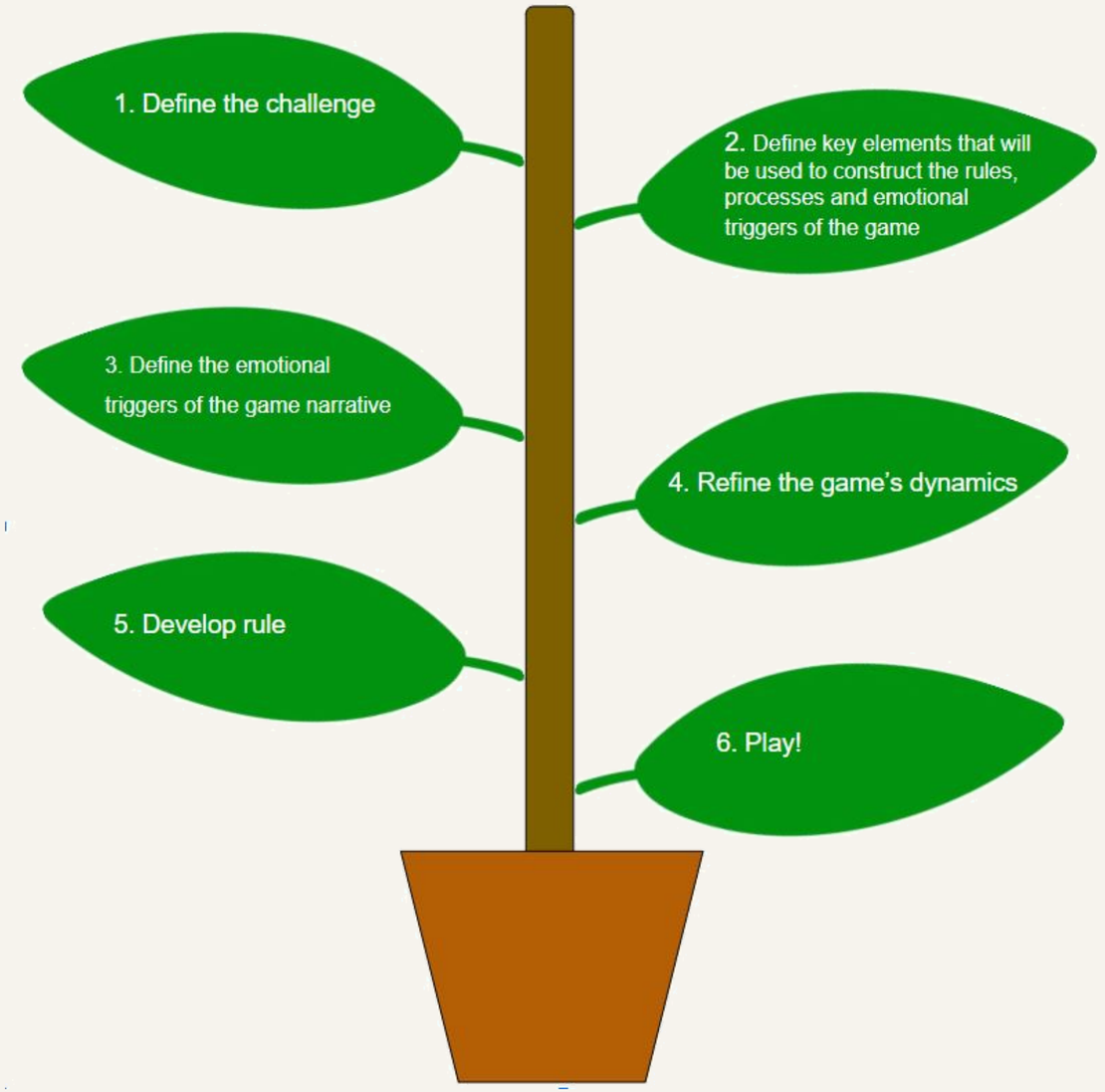


Figure 23. Participatory Game Climate Centre Design Process

COPI's Flood Mitigation and Canal Cleaning Project

Our co-sponsor COPI is a community-based non-profit organization founded in 1999 by Maricruz Rivera Clemente, a social worker and sociologist. COPI is committed to finding alternative solutions to social and environmental problems in Piñones to improve the quality of life of residents, families, and visitors. In response to Hurricane Maria, COPI started the Flood Mitigation and Canal Cleaning Project to conserve mangroves to support local ecosystems and for protection against natural disasters. This CBMM project for the Piñones forest started in 2019 and began Phase 1, restoration and reforestation, in July, 2021.

In this initiative, Marcos Peñaloza works with local scientists, community members, social groups, and four other COPI employees to preserve the health and wellbeing of the largest mangrove forest in Puerto Rico. Five COPI employees maintain a mangrove nursery, clear debris from canals, plant saplings, and document mangrove growth. COPI co-manages the mangroves with the Departamento de Recursos Naturales y Ambientales by growing red mangrove saplings in a nursery and planting the saplings in different reforestation zones around Piñones. The initiative is documented in the Flood Mitigation and Canal Cleaning Project report authored by Marcos Peñaloza.

Figure 24. Explanations being Given in the Clemente Canal

LimPiaR

Our other co-sponsor, LimPiaR, is a non-profit organization created in 2018 as a response to the large amounts of trash found along the coastline of Piñones after hurricane Maria (Figure 13). Spanish for “clean up,” LimPiaR was created to fight pollution through clean-up efforts and by promoting public discussions around recycling and waste management As part of LimPiaR’s mission to create a “cleaner and greener” Puerto Rico, they are focused on providing robust environmental education. A leader and educator at LimPiaR, Auraluz Guzman, is currently working towards raising environmental awareness through the implementation of environmental games with young children in Piñones.

Figure 25. LimPiaR Beach Clean Up with WPI students.

Figure 26. Our team looking at mangroves over the Piñones Boardwalk

Our Project

We pursued a project that combined support for COPI's Community-Based Mangrove Management project with LimPiaR's environmental education initiatives. The goal was to utilize local knowledge about mangrove maintenance and environmental education to develop participatory games and a wave tank simulation that demonstrates the importance of mangroves in Piñones.

Chapter 3: Methods

1

Identifying Community Priorities in Mangrove Restoration in Context to the Piñones Community

2

Understanding the Mangrove Reforestation Initiative at COPI

3

Increase Community Engagement through the Development of Environmental Games

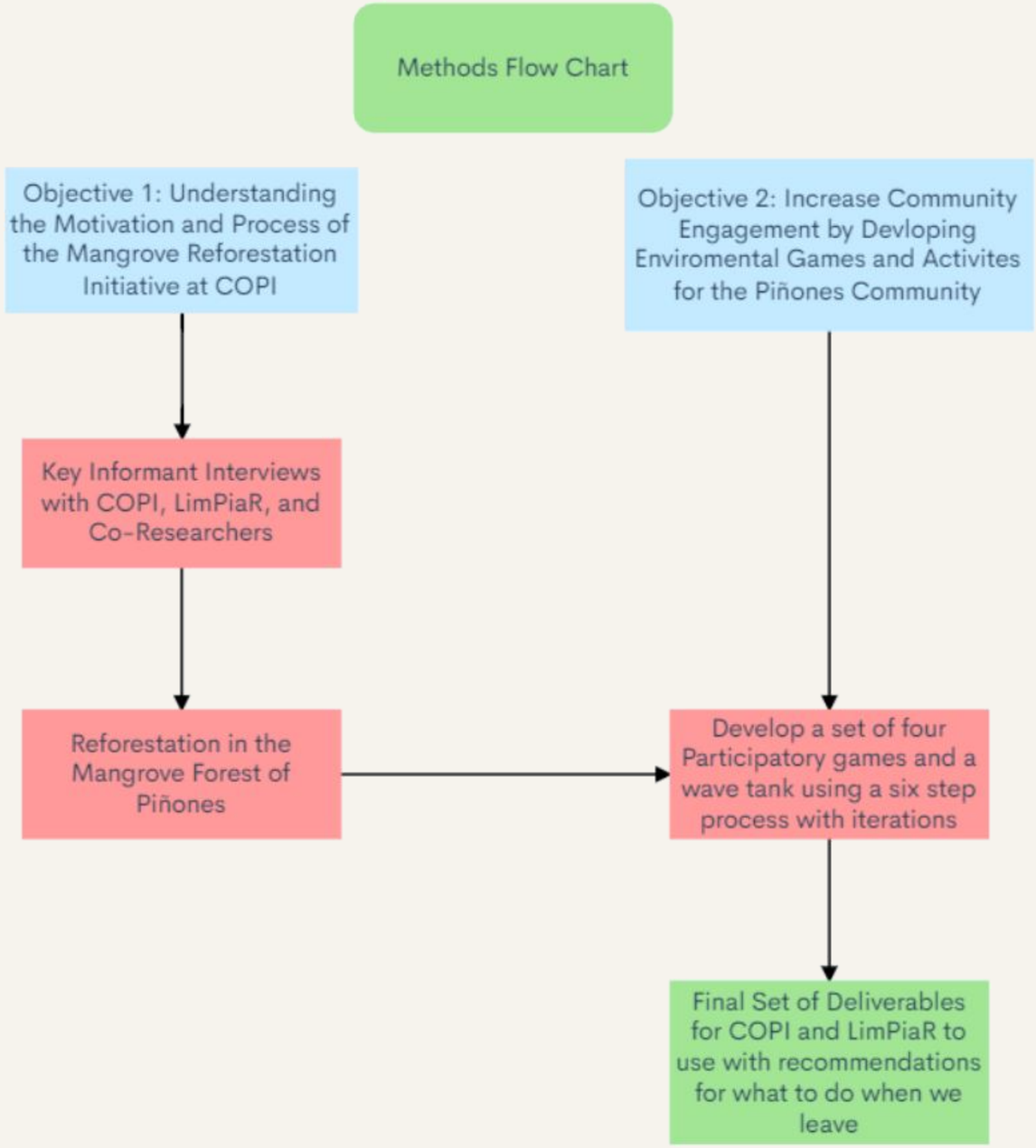
4

Assess the feasibility of designing and constructing an interactive exhibition for COPI that alerted people to the benefits of mangroves

Methods

We collaborated with our co-sponsors, COPI and LimPiaR, to increase accessibility of mangrove education by developing and testing participatory games and an interactive wave tank. We also developed learning outcomes for games and facilitation guides.

Throughout our project, we worked closely with three co-researchers, Angel A. Berudez Gagot, Shawn Escalera, and Paola Rolon Diaz. They participated in field research, helped develop and test participatory games and assisted with translation. They provided the viewpoint of community members who did not previously know about the work being done on mangrove reforestation.



Identifying Community Priorities in Mangrove Restoration in Context to the Piñones Community

Key Informant Interviews

Key informant interviews, used to gain expert information on specific topics, provided our team with necessary background on COPI's mangrove management initiative. We conducted a total of four key informant interviews with Marcos Peñaloza, Maricruz Rivera Clemente, Nuria Escalera, and Auraluz Guzman. These interviews were conducted at COPI, the Clemente Canal, the Piñones boardwalk, and the Peninsula of the Fishermen. Interview protocols and notes can be found in Appendix A and B.

Figure 27. Front of COPI

Key informant: Marcos Peñaloza

Marcos Peñaloza is spearheading the mangrove reforestation effort with the help of four other COPI full-time paid employees. Marcos and his team have been working on the reforestation of mangroves in Piñones for approximately two years. He shared insights into his research (which can be found in his report Flood Mitigation and Canal Cleaning Project report) and experience working with mangroves. Marcos provided information on the threats to mangroves specific to Piñones, the importance of mangroves in different locations, and the methods of mangrove management employed by COPI.

Figure 28. Photo of Marcos Peñaloza

Key informant: Maricruz Rivera Clemente

Figure 29. Photo of Maricruz Rivera Clemente

Maricruz Rivera Clemente is a sociologist and social worker as well as the founder of Corporación Piñones Se Integra (COPI). Maricruz has lived in Piñones, Puerto Rico for a long time and currently lives in the La Torre community. From her time in this community, she has witnessed and addressed the environmental problems in the community. Because of Maricruz's environmental protection work, we looked to her for insights about the community and ways in which ELOC and participatory games could support community engagement for mangrove maintenance while still being able to respect and preserve the traditions and culture of Loiza and Piñones.

Key informant: Nuria Escalera

Nuria Escalera is a part-time employee of LimPiaR and a community leader in Piñones. Nuria works with LimPiaR and has lived in Piñones for most of her life. She provided information on the impacts of tourism, coastal development, natural disasters on the mangroves and the importance of mangroves for community protection and how mangrove regulations affected how community residence relate to mangroves.

Figure 30. Photo of Nuria Escalera

Key informant: Auraluz Guzman

Figure 31. Photo of Auraluz Guzman

Auraluz Guzman is a leader and educator at LimPiaR focused on implementing environmental educational outreach in the community. She has experience in the use of participatory games for environmental learning. Given her knowledge in educational outreach materials, we worked closely with Auraluz Guzman to prototype and develop the participatory games that LimPiaR and COPI will use and distribute. In addition to a key informant interview, we had many sessions with her in which we went over game development, frameworks, and a variety of testing protocols.

Interview Analysis

The conversations we had with our key informants did not follow a structured or semi-structured interview process. Instead, our interviews were held during sponsor meetings and while we conducted field research. This allowed us to ask questions appropriate to the locations we visited. We collected hand-written notes from these meetings and coded them for eight categories: importance, past usage, history, benefits, threats, ecology, education, and community involvement.

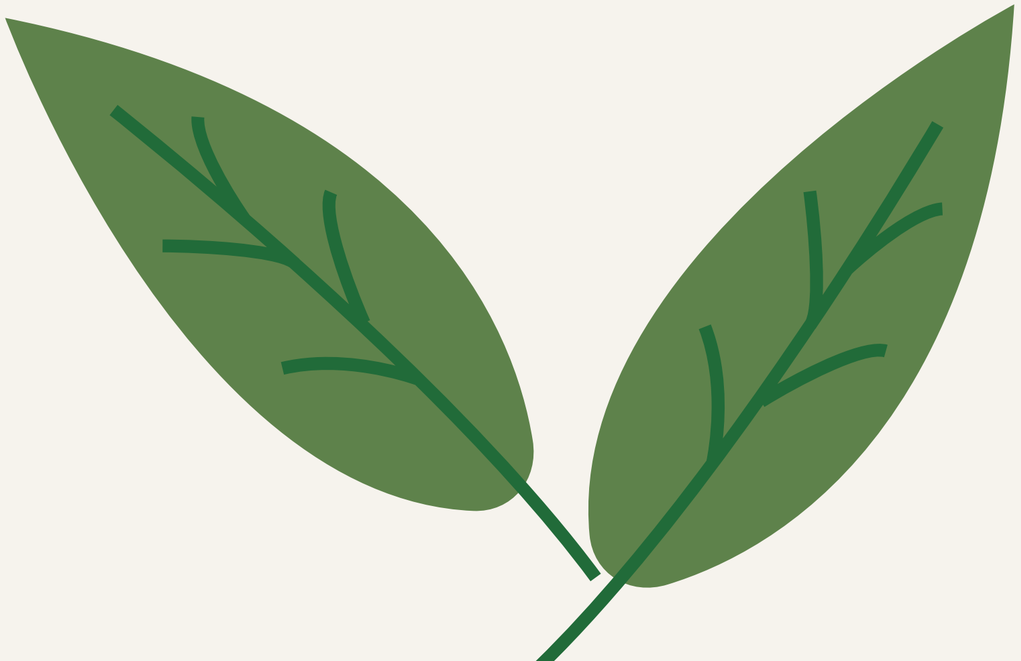


Figure 32. Categories of the information found during interviews about mangroves in Piñones

Understanding the Mangrove Reforestation Initiative at COPI

Participatory research was used to gain experience and information on the specifics behind mangrove reforestation and to form an understanding of mangrove management. Our team worked with the COPI reforestation team and engaged in field research on five separate days to learn more about the mangrove forest, the reforestation process, the importance of management, and viewpoints on how the community interacts with them. We worked in the Clemente Canal, the Piñones Boardwalk, and the Peninsula of the Fishermen. In all these locations, our team helped plant red mangroves to protect the coastline. As we worked in these different locations, we asked Marcos Peñaloza a variety of questions including:

What types of mangroves inhabited the zone?
How were they helping the community?
Why had they declined in interest?
How had the community interacted with the mangroves?
What human activities were damaging mangroves?

These questions along with others that we asked while doing field research can be found in Appendix B.

Figure 33. Marcos Peñaloza explaining the process of planting a red mangrove

During this immersive field work, we learned about, and participated in, the planting processes for different zones and mangroves. We assisted in identifying zones based on observing sections of canals or coastlines that had seen a noticeable decrease in the health of the mangroves or ecosystem. The zones were marked off and reforestation efforts were done taking into account suitable mangroves. We transplanted red mangroves that had been grown in the nursery as saplings which involved digging a hole between 6 and 12 inches into substrate, removing the mangrove sapling from its container, and quickly placing it into the hole before covering it with more substrate (Figure 34).

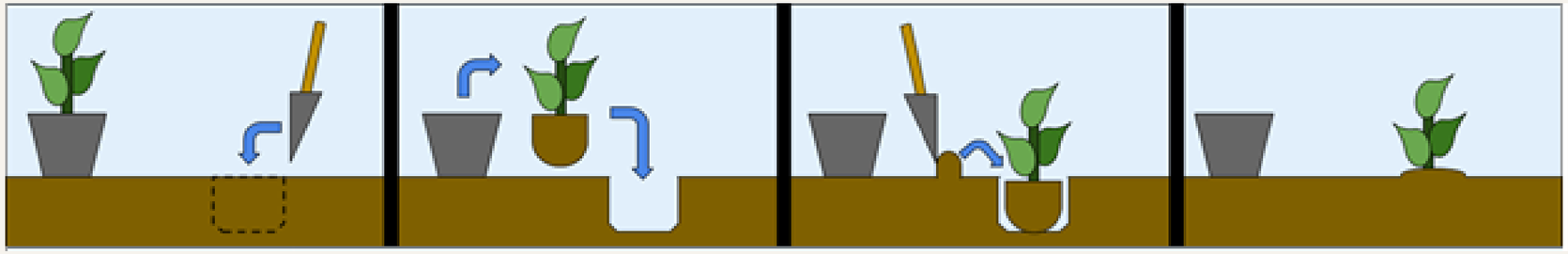
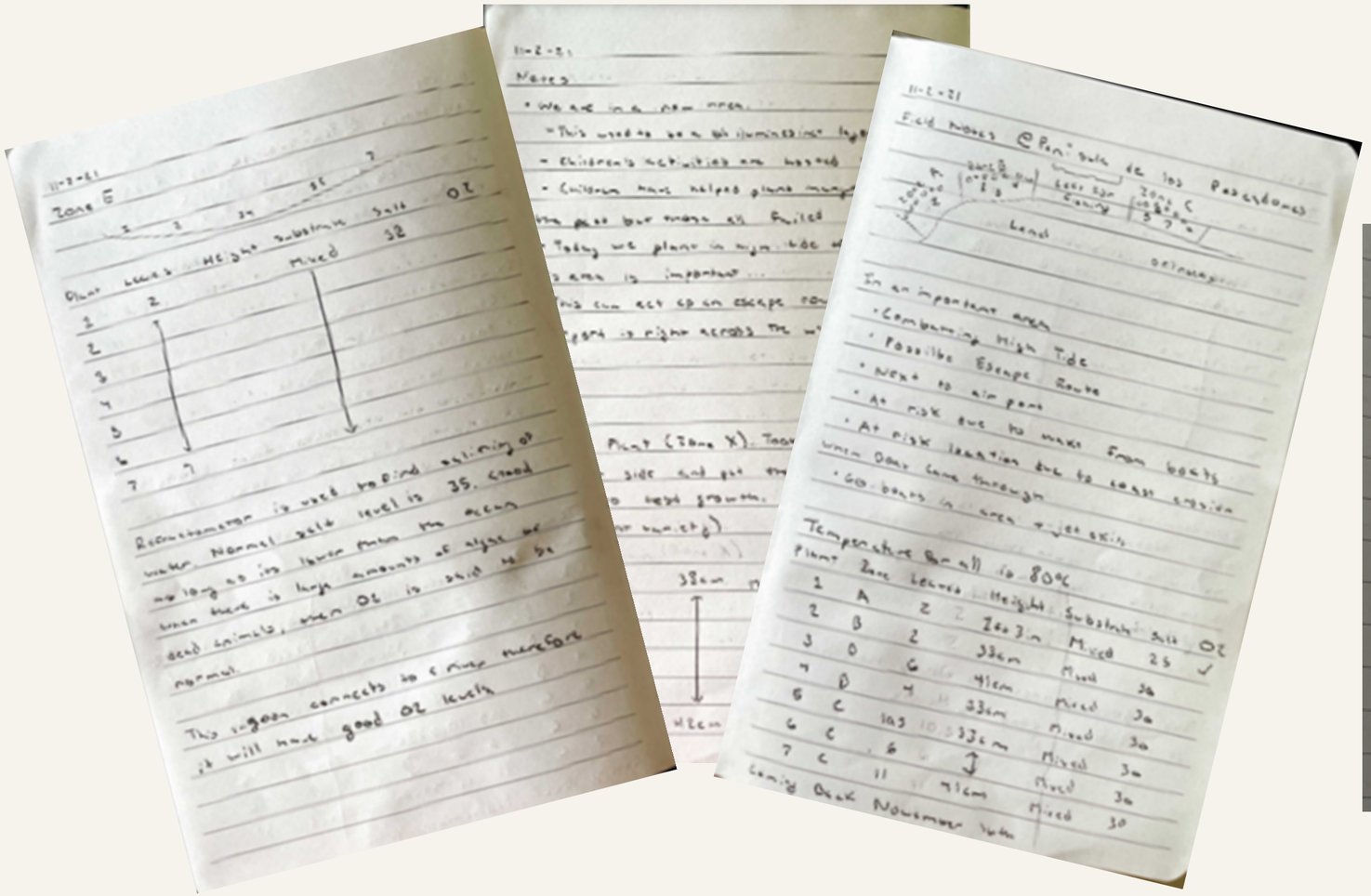


Figure 34. Red mangrove planting process

We also participated in white mangrove reforestation process, which was different. Seeds were initially collected and stored in buckets to allow them to sprout. These sprouted seeds were then scattered across a zone with the expectation some would affix to the ground and develop into plants.

On subsequent trips to the zones, we monitored the status of the planted mangroves, taking note of their development and the number that failed to survive.



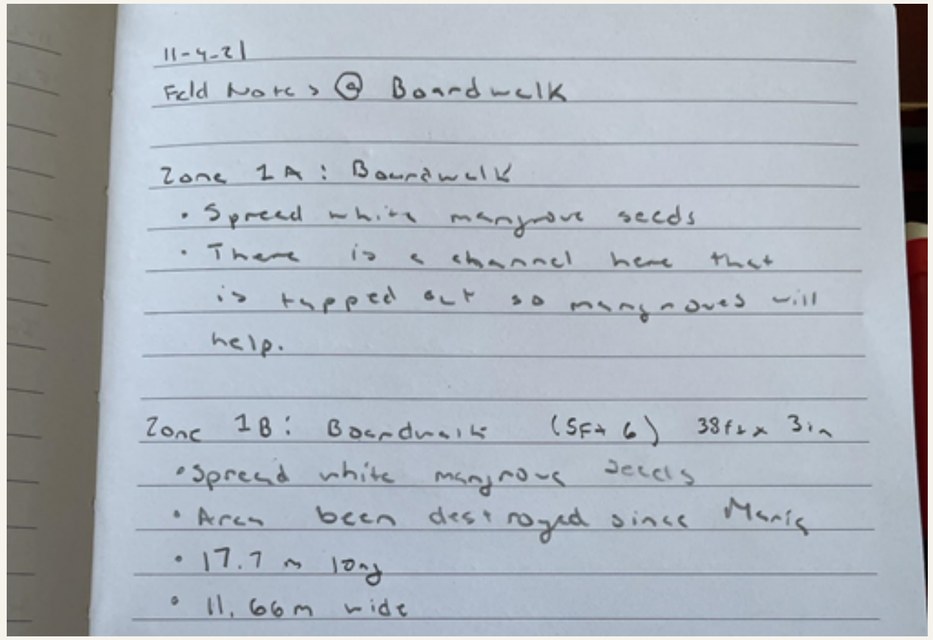


Figure 35. Collage Hand Written Field Notes

Increase Community Engagement through the Development of Environmental Games for the Piñones Community

To engage the community in the topics of mangrove reforestation, we developed prototype educational materials using a set of frameworks. These frameworks were focused on Environmental Learning Outside of the Classroom (ELOC). Developing participatory games and the interactive wave tank represents a form of ELOC.

Participatory Games

We prototyped and tested participatory games to educate players about mangrove ecology and reforestation in a playful manner. The use of games promotes engagement and effective learning as an active method of spurring community interaction (Tsai et al., 2021). We developed game prototypes with the help of our sponsors and advisors based on information we learned about mangroves during our work in the reforestation zones.

We also incorporated information from interviews, and the COPI grant proposal document into games focusing on the importance of mangrove reforestation, the threats to mangroves, and the ecology of the mangrove forests specific to Piñones.

Our prototyping process involved numerous steps. We initially developed eight games, which we narrowed down to four games after discussions our advisors and sponsors. Focusing on prototyping four games allowed for us to increase depth and complexity in games to better represent the complexity of the mangrove management process due to the threats faced by mangroves and the benefits that mangroves provide to the community.

The method that we choose to develop, test, and evaluate our games was based on the Climate Centre's development process (Bachofen et al., 2012), and the e-VITA development process and evaluation frameworks (Pappa & Pannese, 2010). The main purpose of using these methods was to allow our group to have a set process for development and iteration for our games.
The Climate Centre development process is a 6 step process to define, develop, create, implement, evaluate, and iterate games (Figure 36).

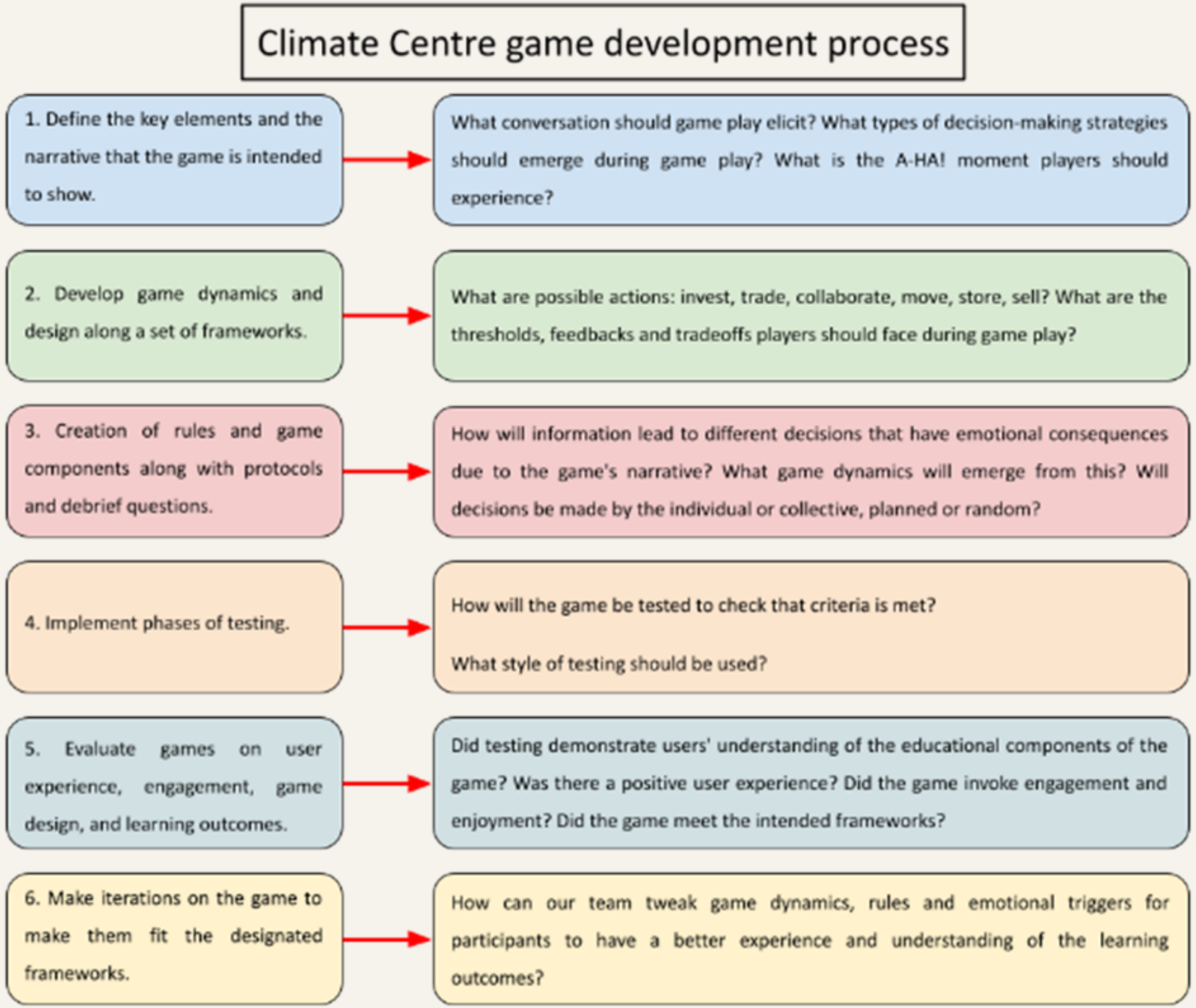


Figure 36.Climate Centre game development process（Bachofen et al., 2012）

In addition to the Climate Centre process, (Figure 36) demonstrates the steps we took to develop, test, and evaluate our games based on the e-VITA development process (Pappa & Pannese, 2010). Made to develop serious games, which prioritize learning over gameplay, for younger audiences, the e-VITA development process is defined as a cyclic method of iterating games (Pappa & Pannese, 2010). After learning requirements are established, a prototype design is created by defining a story, form of learning, gameplay, and graphics. This is followed by testing and improvements that analyze and modify requirements, necessitating a new round of design alterations and testing. The process continues until evaluation frameworks meet goals and a final iteration has been produced (Pappa & Pannese, 2010).

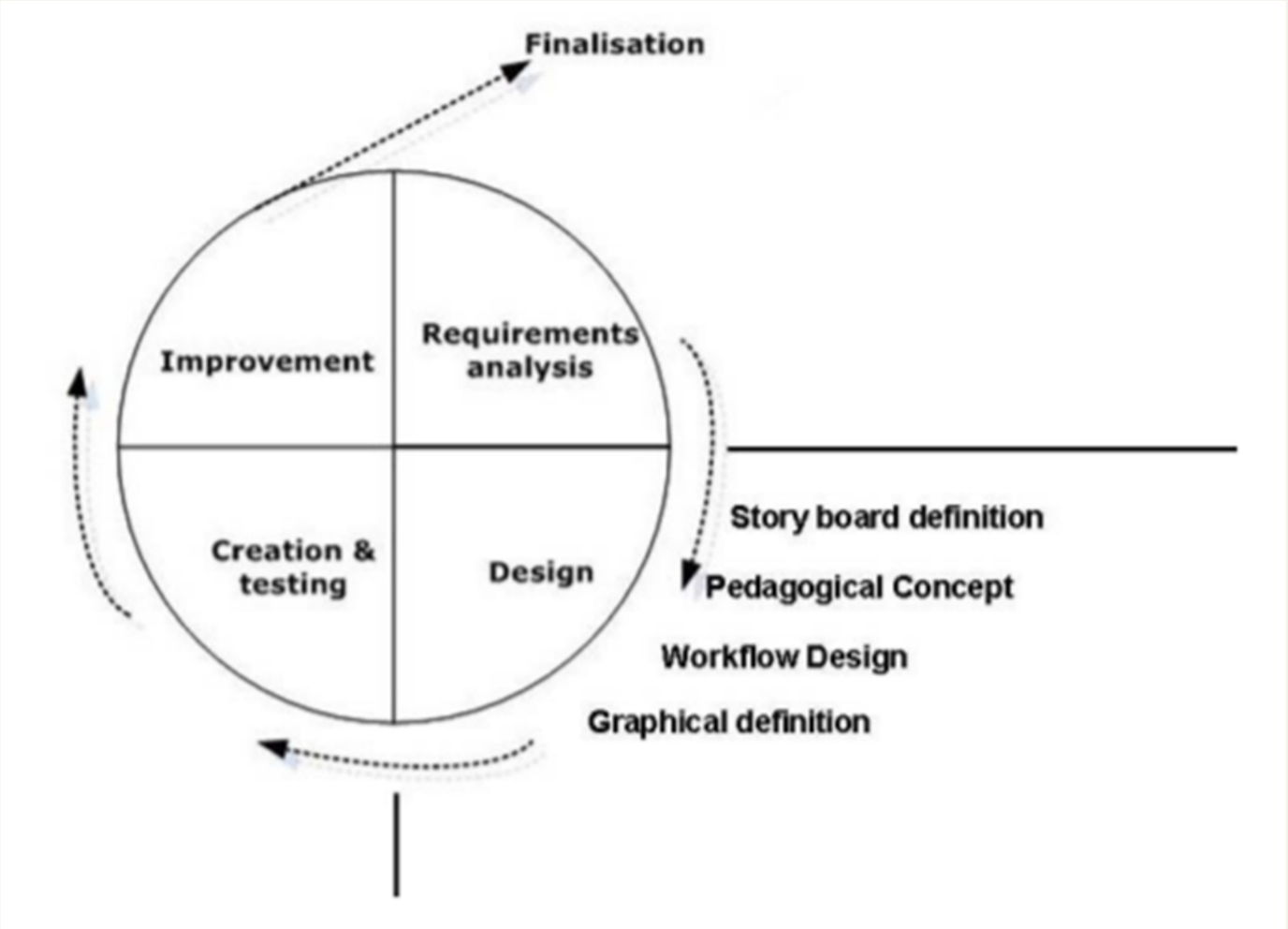


Figure 37. e-VITA development process (Pappa & Pannese, 2010)

For each of our games we started in the requirements section to develop the intended learning outcomes. This included meeting with our advisors and sponsors to go over the concept of the game and the games intended educational message. After that, we created components, rules and debrief questions for each game. We tested these initial prototypes with four groups of volunteers including co-researchers, community members, visitors, advisors, and WPI students to evaluate the games based on user experience, game enjoyment, and learning outcomes. Early-stage games were made from cardboard, cereal boxes, string, tape, and printer paper. These low-fidelity games allowed us to easily test game play, game scenarios and to work out the learning outcomes. We iterated on our games to address questions, comments, and concerns observed during initial testing. Once we completed this cycle of iterations, we finalized the game with better graphics. This process took place for all four of our games: Mangrove Juggle, 7 Day Mangrove, Unstable Mangroves, and Web-of-Life.

Evaluation

We evaluated user experience, game engagement, game design, and achievement of learning outcomes. We utilized the e-VITA evaluation framework which stressed three primary factors (Pappa & Pannese, 2010).

1. Technical verification
    1. While e-VITA uses this in the context of digital games, for our evaluation purposes technical verification is related primarily to the physical game design elements; for example, evaluating the physical game pieces players place on a board.
2. User experience evaluation
    1. e-VITA defines user experience to be primarily centered around the ease of understanding, player engagement, difficulty, and player satisfaction.
3. Pedagogical aspects
    1. e-VITA defines pedagogical evaluation to be based around evaluating how well learners achieve learning goals. Evaluation is based on teacher/facilitator assessment of the player's understanding of learning goals, completion assessment of whether players are able to complete the game, and in process assessment of how players choose their actions and decisions.
    2. To provide flexibility for this process, teacher observations through discussions and debrief was used as opposed to other methods such as a written examination for evaluating player understanding.

We developed debrief questions to elicit responses about participants' user experience, game engagement, and understanding of learning outcomes. Along with our debrief questions, we had a secondary facilitator present at all rounds of testing to take notes on how participants understood the rules and their observed enjoyment and engagement during game play. The notes from game play and debrief were then compiled together for review. Based on these results, we would then re-prototype our game to make it better fit our criteria and frameworks for game play, game design, and learning outcomes.

Assess the feasibility of designing and constructing an interactive exhibition for COPI that alerted people to the benefits of mangroves

An educational wave tank built and displayed at COPI would serve the purpose of acting as a “hook” for catching the attention of community members and visitors at COPI. Additionally, the wave tank would teach about how mangroves protect coastal communities from tidal surges and flooding. A tank exhibition at COPI would act as a natural way of connecting community members to additional sources of mangrove education and the reforestation initiative at COPI. We designed and built the tank with Marcos Penaloza, Paola Rolon Diaz, and Angel A. Berudez Gagot. Through our conversations with Marcos and initial testing of different designs, we came up with a final design that we were able to build and display at COPI.

Building the Tank

Partly due to the standardized sizing of acrylic sheets, we created a tank that is four feet long, one foot wide, and one foot tall. We determined that a four-foot tank was long enough to provide sufficient space for waves to form and diminish before reaching the other end of the tank. Any larger than four feet long may have led to structural issues or taken up too much space. The tank was made with quarter inch thick clear acrylic sheets and Weldon-30 acrylic cement. We chose to create the tank with acrylic as it is an easy material to work with, relatively cheap, and it is typically used for similar projects like creating custom aquariums (Figure 38).

Figure 38. Outline of the wave tank build

Chapter 4: An Environmental Learning Outside of the Classroom Portfolio

1
Mangrove Juggle

2
7 Day Mangrove

3
Unstable Mangroves

4
Web-of-Life

5
Magnífico Tanque de Mangles

Mangrove Juggle

"Mangrove Juggle" was designed to explore the dangers to mangrove ecosystems and how compounding effects can negatively impact the forests to a point beyond management. In its development, we included common threats to mangroves around the globe, such as pollution and hurricanes, while also including Piñones specific issues we discovered during our field work and interviews such as large wakes from boats and pollution from septic tanks. The threats that were used were determined through background research, interviews, and field research (Figure 42).

The 'Mangrove Juggle' game, modeled after the Red Cross/Red Crescent Climate Centre's game, Farming Juggle (Climate Centre, 2017), is a dynamic group exercise where participants toss tennis balls to each other. The game was designed to explore the dangers to mangrove ecosystems and how compounding effects impact the forests to a point beyond management. This game is played by gathering 10-15 participants ages 10 and up into a circle. A facilitator then explains that everyone in the circle is part of a coastal community managing threats to mangrove forests. The facilitator will periodically introduce a new threat facing mangroves, represented by an additional tennis ball that the group must toss without dropping. This is done until the amount of tennis balls becomes too overwhelming for the group to manage.

Figure 39. WPI Students playing Mangrove Juggle

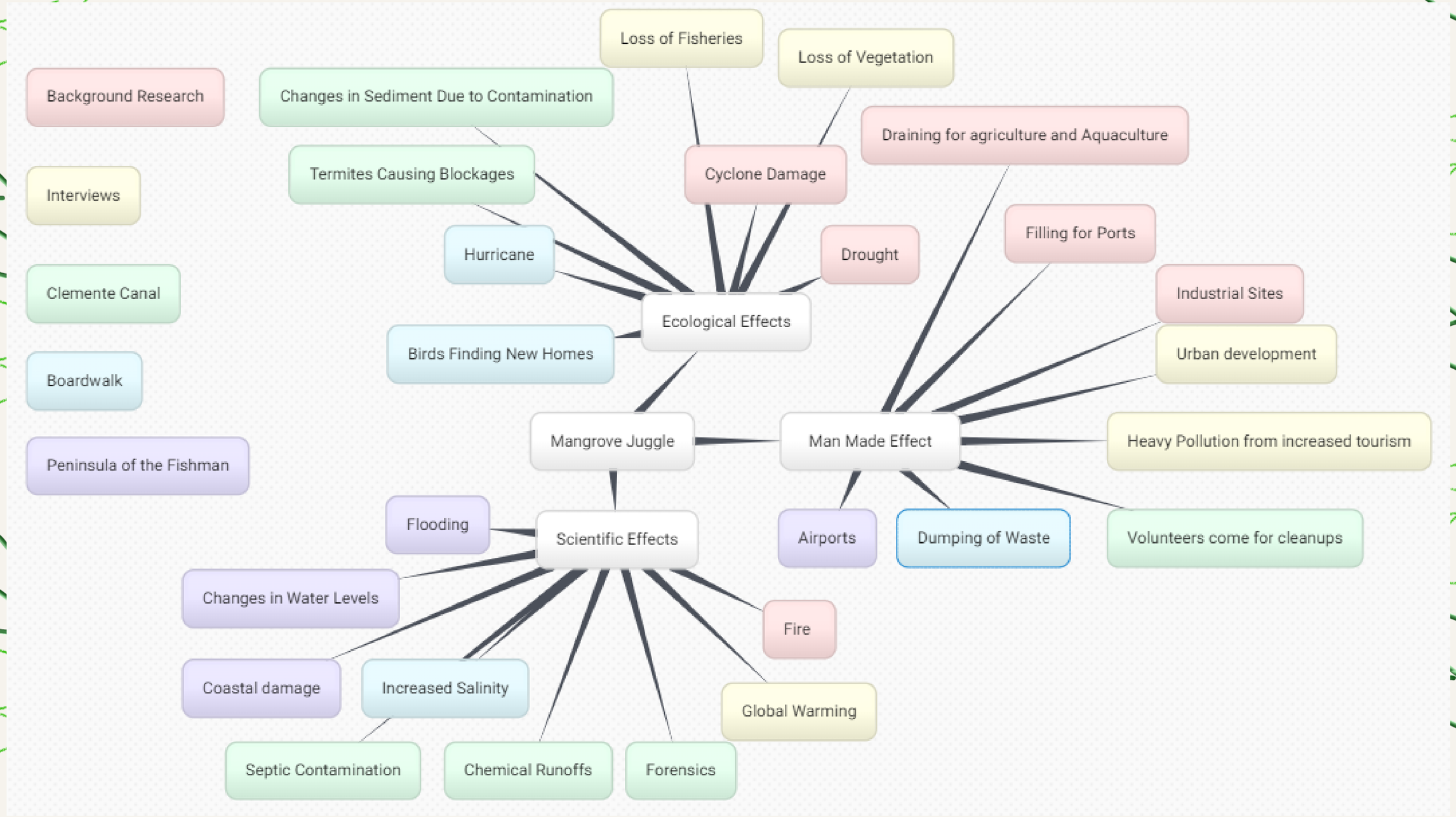


Figure 40. Graphic of Information for Mangrove Juggle by Location

7 Day Mangrove

The 7 Day Mangrove game was designed to teach players the types of mangroves, how mangroves protect communities from storm surges, the threats to mangroves from primarily human causes, and how they are helped by reforestation practices. Included in the game are threats such as the effects of contamination, boating wakes, land development, logging, and rapid salinity changes. The game also includes reforestation practices such as soil usage, a nursery, seed gathering, volunteer groups learned during our time conducting field research in the mangrove forest, and protecting saplings from waves with boulders.

In this 3-player cooperative board game players assume the role of a reforestation program. The goal of the game is to plant a suitable number of the three types of mangroves in their respective zones to protect the community from sustaining damage from an imminent storm surge. To accomplish this, each player is responsible for one row of mangroves which represent one of the mangrove species. Each turn, players roll an eight-sided dice to determine how many seeds they obtain, and then choose whether to invest seeds in a nursery to obtain more saplings or save their seeds. The player draws an event card, which may hurt the mangroves in a random location or provide a benefit, and then chooses if they want to plant their seeds in a zone or save them. Once all three players have chosen their actions in this order, the turn ends. After seven turns, a storm surge hits the board and will damage the community if an insufficient number of mangroves are present.

Challenges for the game are provided by the random events, while player actions revolved around planting seeds and saplings, utilizing a nursery, and responding to events.

Figure 41. Community Members and Co-researchers Playing 7 Day Mangrove

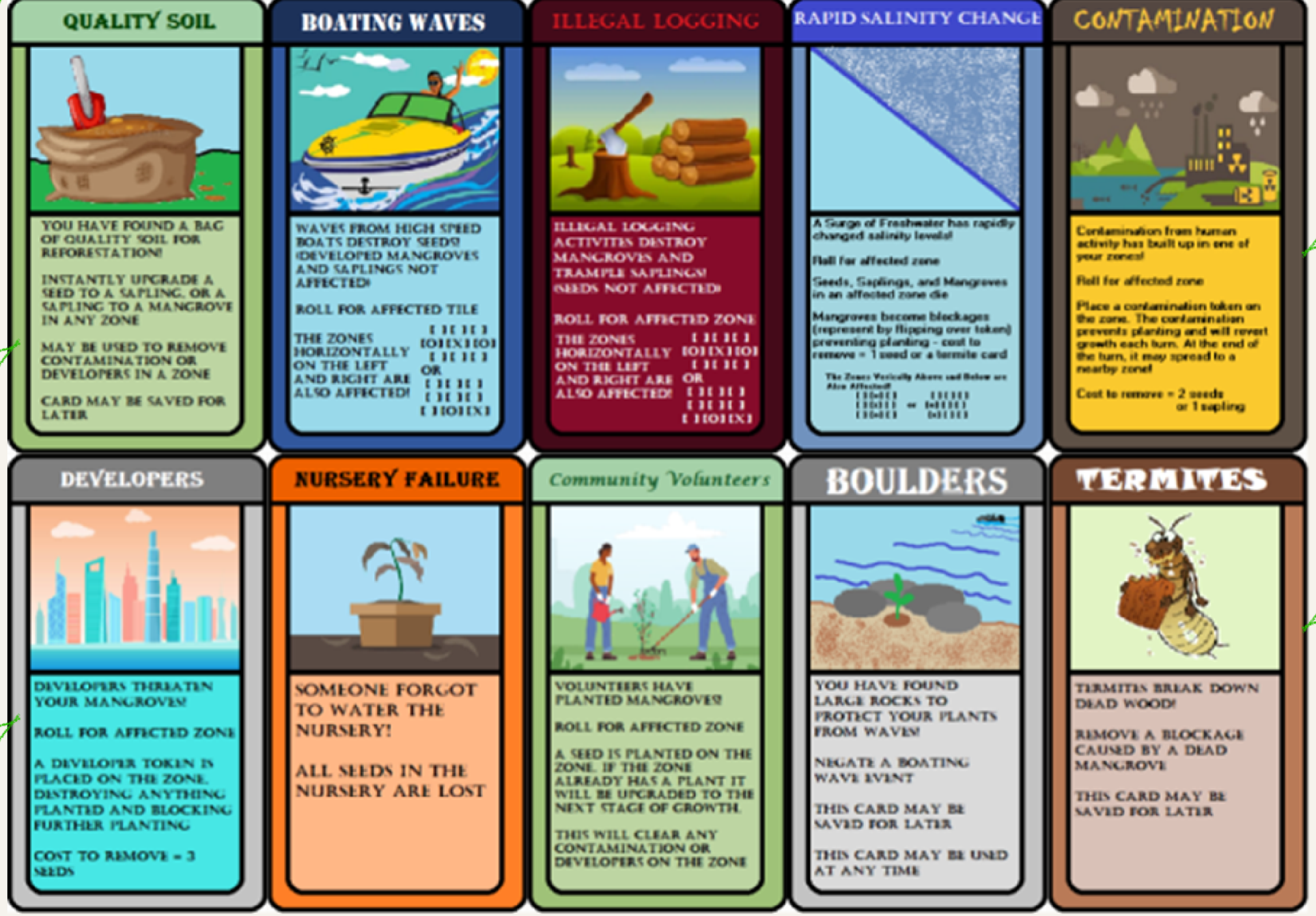


Figure 42. All of the Cards in 7 Day Mangrove

Figure 43. Collage of 7 Day Mangrove

Unstable Mangroves

The learning outcomes for “Unstable Mangroves” are to understand the man-made and ecological threats to mangroves in Piñones and how these can be combated. The purpose of this game is to teach players about the threats in a fun competitive way. The learning outcomes of the game focused on teaching community members about natural and man-made threats to mangroves, as well as ways in which they can directly respond to reverse these threats.

“Unstable Mangroves,” modeled after the game “Unstable Unicorns” by Unstable Games (Unstable Games, 2018), is a card game where four to ten participants play against each other to build up their mangrove forest by collecting cards that benefit their mangrove while sabotaging other participants’ mangroves with cards that would negatively impact their forest. The game is designed for participants of ages ten years or older. Participants sit in a circle with cards laid out based on the instructions. Each player will have to work to build up their own forest with upgrade cards while trying to keep others from having more mangroves by placing downgrade cards on them. This game is played until one participant has enough mangroves in their forest--the space on the table of floor in front of them--to win.

The “Unstable Mangroves” game focused on how threats can be counteracted. One card demonstrating this would be the high-speed boating card and boating speed limit card. While planting mangroves at The Peninsula of the Fishermen, jet skis and boats sped past us, not following the speed limits that were set. When these boats saw that there was a set of people working on planting trees and having to pick up rocks to barricade the trees for the boats, they slowed down. To try and show this action in the game, there is an upgrade card that says boating speed limit set and a downgrade card that says high speed boating. There are people who will not follow the boating limit, setting this limit is one of the best ways to try and combat this issue.

Figure 44. Table Setup for Unstable Mangroves

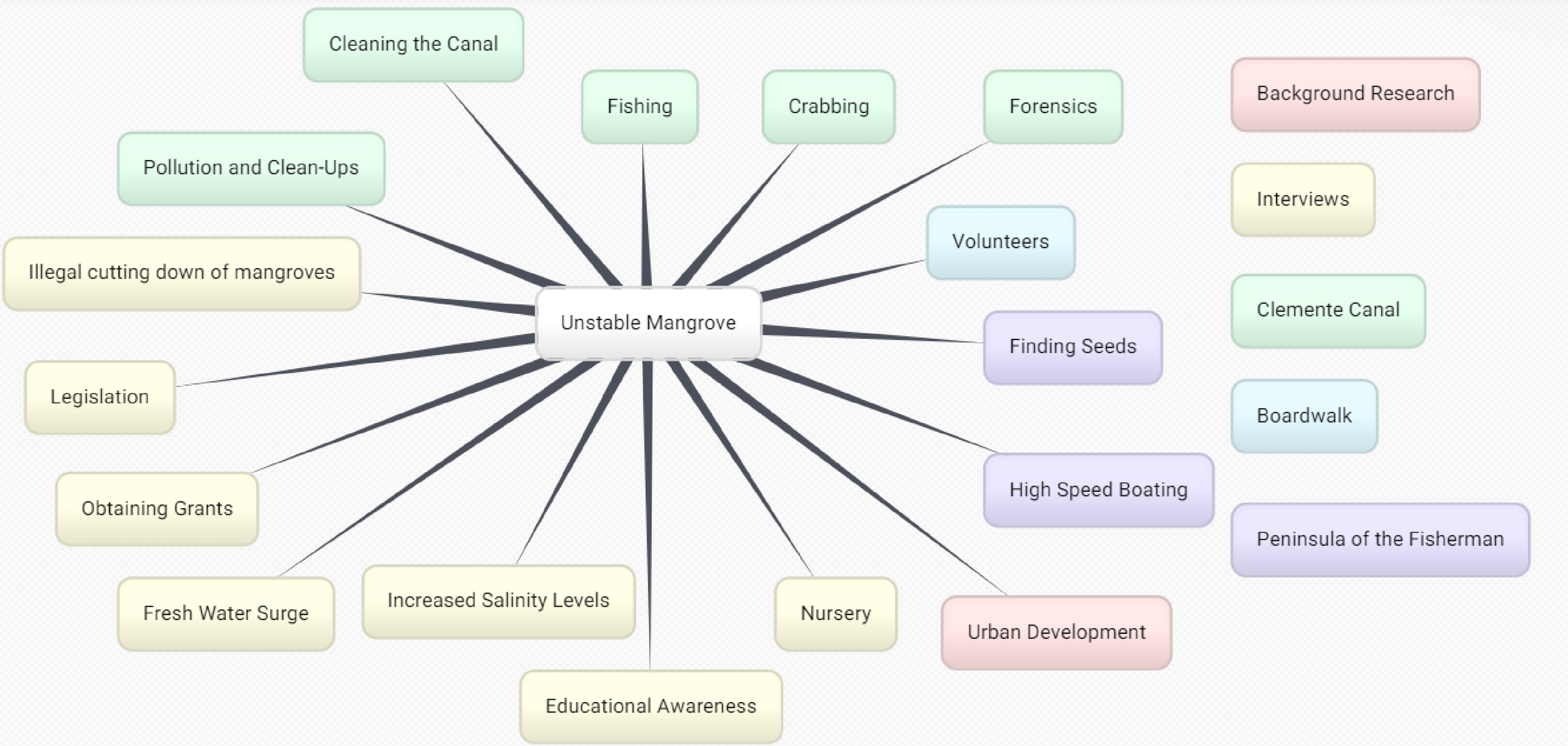


Figure 45. Graphic of Information for Unstable Mangroves by Location

Web-of-Life

"Web-of-Life" is a game suggested by one of our sponsors, Auraluz Guzman, from LimPiaR. This game has been used in the past to demonstrate to children how organisms within an ecosystem co-exist. Our team adapted this game to demonstrate the ecological importance of the mangroves in Piñones.

In this embodied game, intended for children 8 years of age and older, 12 or more participants receive a necklace representing a different organism present in the Piñones mangrove forest. Participants take turns passing around a ball of twine to different organism, explaining how they are all connected. At the end of the game, every "organism" in the circle is interconnected to form a web.

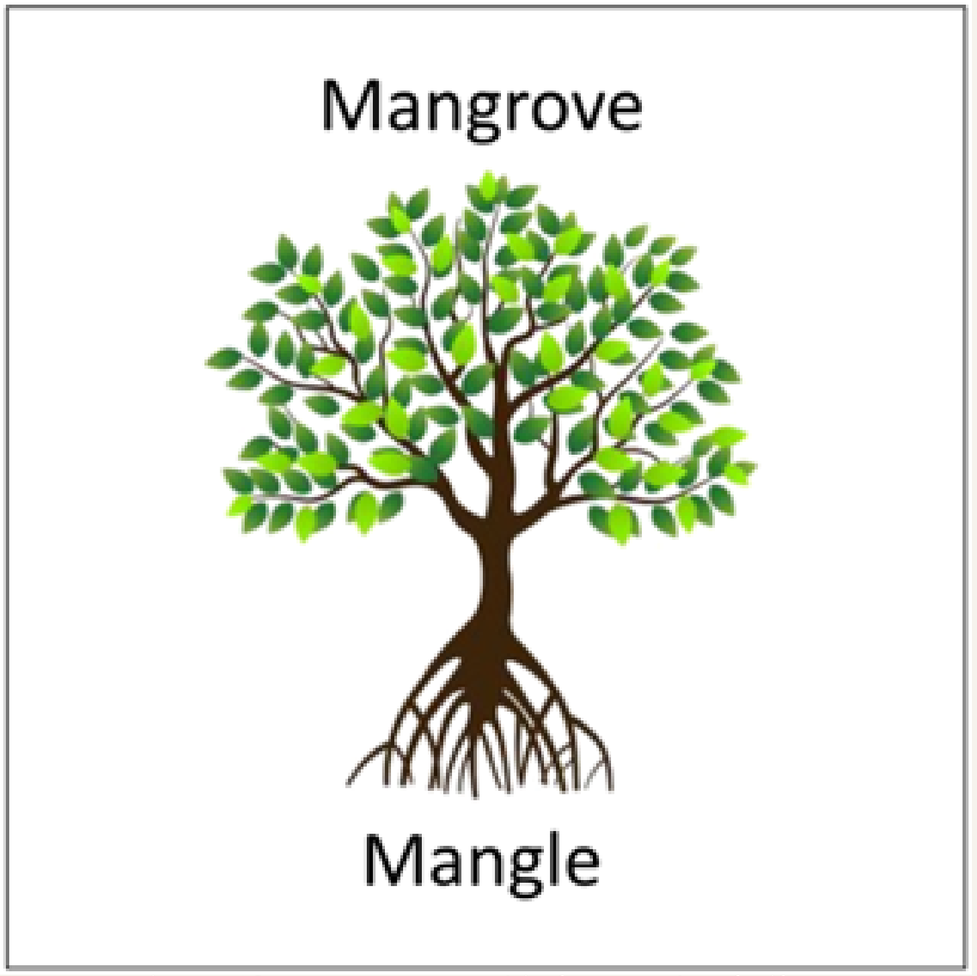


Figure 46. Mangrove Graphic from Web-of-Life

Magnífico Tanque de Mangles

Drawing inspiration from an exhibit by the Dutch Research Institute Deltares (VKT Entertainments, 2019), we developed a small-scale interactive wave tank to exhibit at COPI that demonstrates the importance of mangroves in Piñones. It was designed to demonstrate how mangroves protect coastal communities from flooding and coastal erosion (Figure 49). It does this by having artificial mangroves block waves created at one end of the tank from reaching the other end where a model community is located. The tank itself also serves the purpose of acting as a "hook" for catching the attention of community members and visitors at COPI. This would act as a natural way of connecting community members to additional sources of mangrove education and the reforestation initiative at COPI.

To interact with the Magnífico Tanque de Mangles, users can pull the string at the end of the tank to create waves that propagate towards the "community" at the other end of the tank. The "mangrove forest" in the tank will diminish the magnitude of the waves before they reach the community. To better understand how mangroves prevent flooding, the mangroves in the tank may be removed to observe how the waves act when there is no barrier between the coastal community and the ocean. When this is the case, the waves will crash up the bank of the coast and "flood" the community.

Figure 47. How Mangroves Protect Coastal Communities from Flooding(Sucharitakul & Hardy, 2021)

Mangroves

The artificial mangroves made for the Magnífico Tanque de Mangles were designed and created to increase the interactivity and effectiveness of learning outcomes of the simulation tank. This was done by making the mangrove forest removable from the tank to observe the difference between having mangroves protect the community and not having them.

Additionally, we wanted the mangroves to look as realistic as possible to increase the effectiveness of the demonstration. The mangroves were created with artificial aquarium plants, sponges, and spray paint (Figure 48).

Figure 48. Mangroves for the Wave Tank

Wave Mechanism

The mechanism we designed also increased the interactivity and educational value of the simulation tank. As the user has full control of the plunger, they can create waves with higher or lower magnitude and frequency. The different frequencies and magnitudes of the waves created can represent different types of waves present in nature, from boating wakes to tsunamis. To create the wave mechanism, we affixed a pulley to the top of one end of the tank. A string was then attached to a plastic tennis ball container to act as a “plunger” that can be pulled up and down to create the waves in the tank. The plunger was filled with stones until it was heavy enough to make waves when dropped from the pulley into the water (Firgure 49).

Figure 49. Wave Tank Mechanism in Action

Chapter 5: Findings

The Piñones Mangrove Forest Benefits the Community and is Under Threat in a Variety of Ways

Participatory Tools Can be Effective Tools to Educate Community Members About the Importance of Mangroves

Findings

Interviews with local stakeholders, field research about threats to mangroves in Piñones, and the importance of maintaining these mangroves informed the design and development of four participatory games and an educational wave tank. The environmental games focused on threats to mangroves, the benefits they provide, reforestation strategies and the interconnectedness of organism in the mangrove ecosystem. The development processes for the games were based on various Environmental Learning Outside of the Classroom (ELOC) models. The Climate Centre's game design framework and the e-VITA evaluation framework also informed the development of the environmental games and the wave tank.

These participatory tools were developed and prototyped with our sponsors and local stakeholders then tested with volunteers. Testing allowed us to evaluate the user experience, game engagement, and learning outcomes for each of our games. These tests informed iterations to each of our games to improve them according to their designated frameworks.

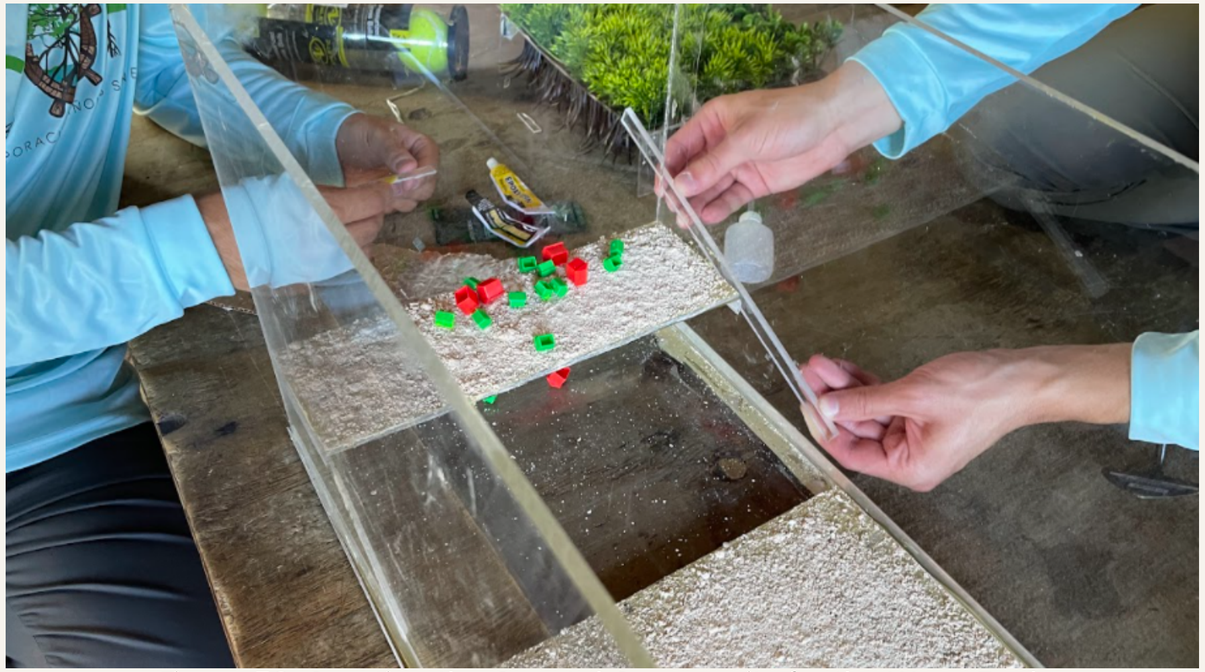


Figure 50. Creating the Coastal Community for the Wave Tank

Field Sites

We set out to understand COPI's Flood Mitigation and Canal Cleaning Project by working with the COPI team and conducting field research and interviews at three different sites: the Clemente Canal, The Peninsula of the Fishermen, and the Piñones Boardwalk, which feature various threats to mangroves, the processes involved in mangrove maintenance, and the varying management strategies in three different zones in the Piñones mangrove forest.

Figure 51. Map of the areas visited 1: Clemente Canal, 2: Peninsula of the Fishermen, 3: Piñones Boardwalk

Clemente canal

The Clemente Canal connects Maria Lagoon to the Torrecilla Lagoon and is accessible through the boardwalk that runs through Piñones. Currently, thirty of the reforestation zones are located along this canal. To access the reforestation zones in this area, we took kayaks through the canal on three separate occasions. During our time working in the canal, we planted red mangrove saplings raised in the COPI nursery in various reforestation zones along the shore while clearing debris from the canal and documenting areas along the coast that may be in need of reforestation efforts. In this area, we observed the vast range of species inhabiting the mangroves while learning about the history of the community's relationship with mangroves and the effects legislation can have on mangrove maintenance. We were informed zones close to the small lagoon are subject to floods, and those near the boardwalk endure contamination from septic tanks. Additionally, without management of mangroves in this area, blockages may form and impede current flow in the canal, which can threaten mangroves if salinity changes occur from heavy rains or floods.

Primary ecological issues in the Clemente Canal:

1. Contamination from septic tanks
2. Excess debris from dead vegetation
3. Loss of wildlife

Figure 52. Kayaking Through Clemente Canal with Mangrove Saplings

Getting to the Canal

Figure 53. Bring Kayaks down the Piñones Boardwalk to the Clemente Canal

Figure 54. Red Mangrove Saplings in Truck to be Brought to Reforestation Zones

Clearing Debris

Figure 55. Reforestation Zone in Clemente Canal Where Debris Needed to be Cut and Removed with a Chainsaw

Figure 56. Clearing Dead Mangroves Near the Piñones Boardwalk to Make Room for Seeds and Saplings

Our team in the Clemente canal

Figure 57. Our Team Kayaking Through the Clemente Canal

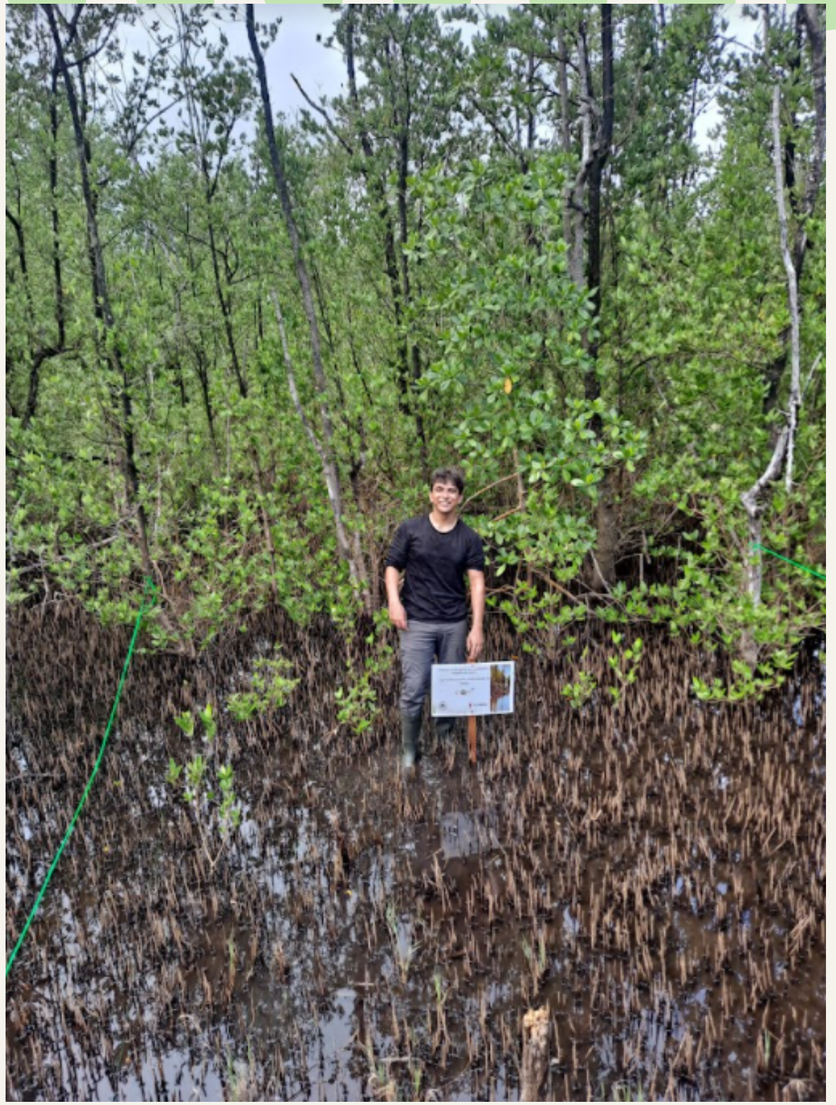


Figure 58. Planting a sign in a New Reforestation Zone off the Piñones Boardwalk

Our team in the Clemente canal

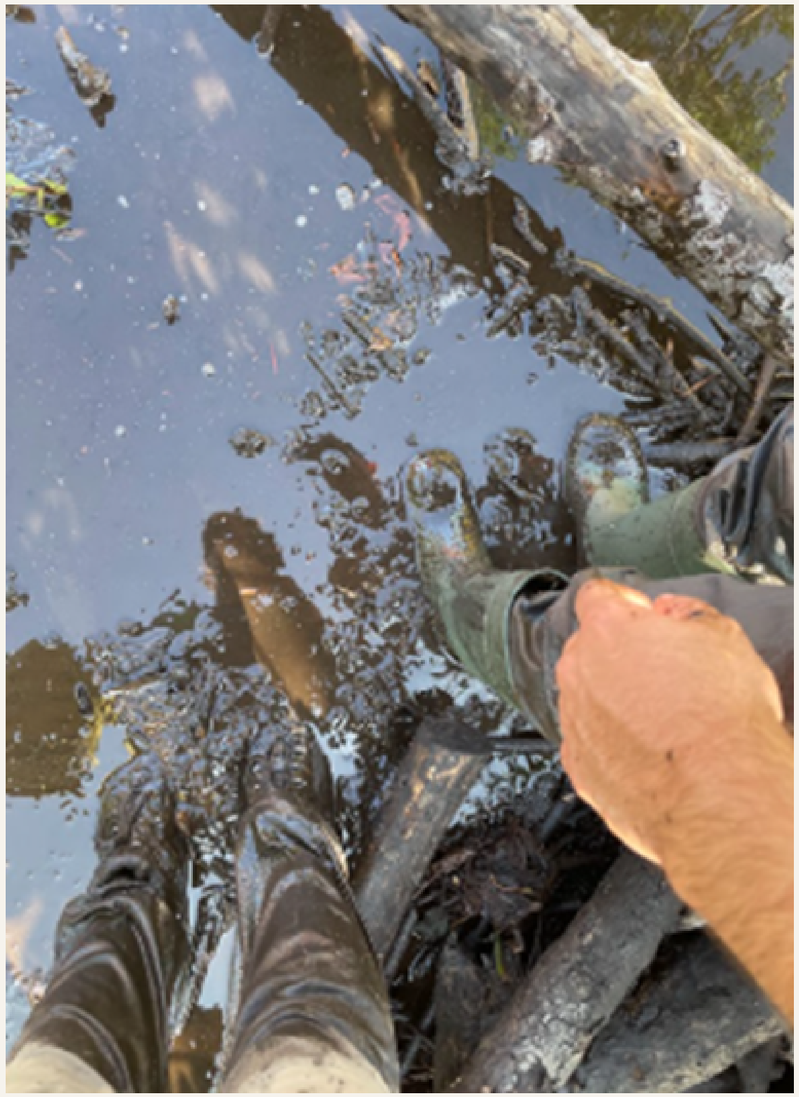


Figure 59. Getting Muddy in the Clemente Canal

Figure 60. Kayaking in the Maria Lagoon

The Peninsula of the Fishermen

We conducted field research in the Peninsula of the Fishermen in La Torre on three different occasions. This is an area of recreation for the La Torre community and educational programs like COPI's Superhero program is held here. At the Peninsula of the Fishermen, we observed signs of land erosion and bare areas where mangroves once stood largely due to the jet skis and boats that pass close by the peninsula and create wakes. While there is a boating speed limit in the area, we found it to be rarely enforced or followed. Directly across from the peninsula is the Luis Muñoz Marín International Airport, a clear sign of coastal development and source of pollution into the Piñones lagoons. We worked with the COPI team to fortify these areas by planting red mangrove saplings that needed to be fortify by rocks to protect the seedlings. Additionally, we found that in this area, there is also an abundance of white mangrove seeds that wash ashore. These seeds can be collected and spread into other reforestation zones where white mangroves will naturally grow and thrive.

Primary ecological issues in the Peninsula of the Fisherman:

1. Pollution and contamination
2. Wakes from boats
3. Erosion
4. The airport across the lagoon

Figure 61. Marcos Peñaloza Measuring the Height of a Recently Planting Red Mangrove Sapling

Example Field Notes

Zone	# of Plants	# of Leaves	Height (Cm)	Salinity(PPT)	Notes
A	1	2	38	25	
B	3	2-6	33-41	30	
C	3	?	?	30	
D	6	2-6	38-42	?	
X	4	--	--	?	Just an experiment, not expected to survive
E	7	2-10	?	32	

This table shows how we collected date at different field site for monitoring purposes. This is used by our co-sponsor COPI for documentation purposes.

- Salinity below 35 PPT is normal (this is the salinity of the ocean)
- The temperature of the water for each zone is 80 Degrees Fahrenheit
- O2 measurements are only recorded in vulnerable areas (this is in confined areas and areas with visible algae growth)
- The substrate for each zone, except X is mixed (sand and rocks)

Salinity Testing

Figure 62. Measuring Salinity Level at the Peninsula of The Fishermen

Zones

Zones are the set out locatioss where mangroves were planted for monitoring purposes

Figure 63. Planting Stakes to Create a Reforestation Zone

Figure 64. COPI's Reforestation Team Marking off a Reforestation Zone

Mangroves our team planted

Figure 65. Red Mangrove Sapling Planted with our Co-researcher, Paola

Figure 66. Group of Red Mangrove Saplings Surrounded by Rocks to Prevent Damage from Boating Wakes

The Boardwalk

South of Piñones and off of the boardwalk, we worked on reforesting an area with visible damage to the mangroves. While walking through the boardwalk, a zone was designated where a large area of mangroves was almost completely dead and in serious need of reforestation. The group visited this zone twice to designate and clean the zone followed by planting. The drastic loss of mangroves in the region was due to the lasting effects of Hurricanes Irma and Maria, showing that larger climate threats endanger mangroves, and large dead zones have trouble recovering. This zone was divided into three subzones and marked for reforestation. As the zone was home to excessive amounts of dead wood and blockages, it needed to be cleared of large debris to make room for new mangroves to grow. Red mangrove saplings were evenly spaced out by approximately one yard, planted with or without containers, and recorded by the approximate height, leaves, and number planted. White mangrove seeds collected from the Peninsula of the Fishermen were spread in these zones as well.

Primary ecological issues on the Boardwalk:

1. Lack of maintenance
2. Hurricane Maria
3. Littering

Figure 67. Planting Mangroves in a Barren Part on the Pinones Mangrove Forest

White Mangrove Seeds

Figure 68. Collecting White Mangrove Seeds at The Peninsula of The Fishermen

Figure 69. Spreading White Mangrove Seeds in a Reforestation Zone

The Piñones Forest: Threats and Benefits

We conducted five interviews with three main stakeholder groups: community members, COPI, and LimPiaR who represent different perspectives on mangrove reforestation. Interviews focused on the importance of mangroves to the Piñones community, past use of the forest, benefits, threats, education, and community involvement. Interview schedules and fieldwork notes can be found in Appendix C Responses informed our games. Four main themes emerged from the interviews, including how mangroves protect the Piñones community; how the community can benefit from the mangroves; how community members and visitors have harmed mangroves; and what the community can learn from the mangroves (Figure 70 & 71).

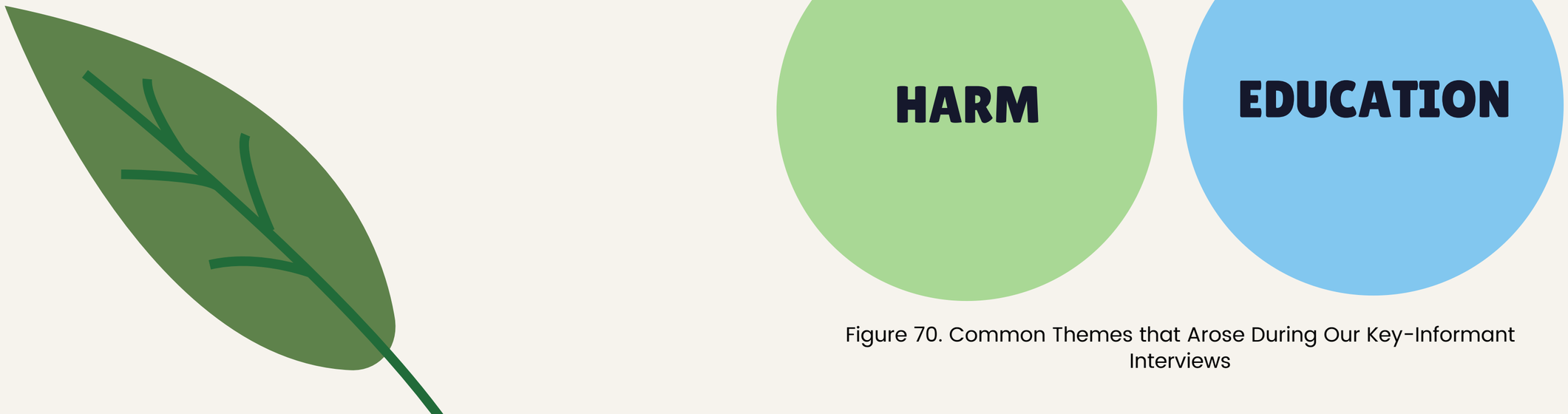


Figure 70. Common Themes that Arose During Our Key-Informant Interviews

Threats and Benefits	Location
Yacht Club (pollution + boat wakes)	COPI
Utilizing a Nursery	COPI
Grants	COPI
Erosion	Peninsula of the Fishermen
Airport (development)	Peninsula of the Fishermen
Coastal development	Peninsula of the Fishermen
Collecting Seeds	Peninsula of the Fishermen
Plastic Waste	Peninsula of the Fishermen
Fresh Water Surges	Clemente Canal
Fast Salinity Changes	Clemente Canal
Excess termites	Clemente Canal
Legislation	Clemente Canal
Septic tank contamination	Clemente Canal
Canal Clean Ups	Clemente Canal
Hurricanes	Boardwalk
Wildlife	Clemente Canal, Boardwalk
Fishing	Peninsula of the Fishermen, Clemente Canal
Crabbing	Clemente Canal, Boardwalk
Clearing out Debris	Clemente Canal, Boardwalk
High Speed Boating	Peninsula of the Fishermen
Volunteers	Clemente Canal, Boardwalk
Educational Awareness	COPI, Peninsula of the Fishermen

Participatory Tools Can be Effective Tools to Educate Community Members About the Importance of Mangroves

We found that our prototype participatory games effectively conveyed the importance of mangroves. To evaluate the user experience, game engagement, and learning outcomes for each game, we conducted game testing with a variety of participants. We incorporated feedback on playability, enjoyment, and educational value into successive iterations of the games.

Frameworks are what we used to test and evaluate our games. These frameworks were involved in the development stages as this is when we wanted to figure out if our games would be more focused on user experience or on game engagement. The frameworks we developed were also talked about with our co-sponsor Auraluz Guzman as we decided what the learning outcomes for each game would be and how they would be incorporated into each game.

Mangrove Juggle

Initial testing of this game was conducted with a group of twelve WPI students and community members at La Posita Beach in Piñones. A full facilitation guide along with debrief questions can be found in Appendix E.

Mangrove Juggle Frameworks:

Criteria	Evaluation Framework
Development	
The game is a playful look at the threats to mangroves in Piñones.	Game Design ● Were the components of the game interesting? ● Could more components be added or taken away to change up the game? ● Could we add in more colorful balls? ● Could we add in game setbacks such as half of the group kneeling or having to take three steps back?
Game Dynamics	
Players are able to throw and catch a ball while listening to the facilitator explain threats to mangroves.	User Experience ● Are users able to understand the rules of Mangrove Juggle? ● What issues arose from having balls being thrown around the circle? ● Was the game safe to play with the set age group involved? ● Were participants listening to the negative impacts that the facilitator was saying?
Game play is fun, safe, and lighthearted.	Game Engagement ● Did users enjoy throwing the ball around? ● Was everyone comfortable with a ball being thrown at them? ● Did users appear to be having fun while playing?
Educational Material	
Players learn about the threats to mangroves and the importance of communication and working together.	Learning Outcomes ● Threats to mangroves ● When there are more threats, it is harder for the forest to maintain everything that is happening (ie. the ball drops) ● The community needs to work together and communicate to manage threats ● There are many types of threats to mangroves: ○ Man-Made threats ○ Scientific Threats ○ Ecological Threats

The first play test of this game was conducted with a group of twelve WPI students at a beach clean-up hosted by LimPiaR. We observed that the hectic nature of the game made it difficult to listen to what the facilitator was saying. Since the players could not hear the facilitator, the intended learning outcomes were not achieved. To achieve learning outcomes, the rules were changed so that the facilitator stops the game before announcing the event and adding a ball to the game. Another possible way of doing this which was suggested to us by Auraluz Guzman, is to play music during the game and when the music stops, so do the participants. It was determined that for younger participants playing music might be too stimulatory. Therefore, we have left it to the facilitators discretion on whether to use music to stop the game or to tell players to stop playing.

Additionally, the game proved to be more difficult than originally thought, which negatively impacted the user experience but positively affected user engagement. This was determined as our secondary facilitator noted that participants failed to keep the balls from touching the group after just three balls were added to the circle. When the game was in the development stages, we predicted that players would be able have about five balls moving around the circle before they started dropping. Therefore, we changed the minimum suggested participants from 10 to 12 players.

Due to the large number of players needed to successfully run this game and the limited amount of time we had to test the game; we were only able to run one round of testing.

Figure 71. Playing Mangrove Juggle Outside of COPI

7 Day Mangrove

The 7 Day Mangrove was designed to demonstrate how mangroves protect communities from storm surges, are threatened, and are helped by reforestation. The development of the game included concepts we learned from the literature and our key informant interviews, such as the effects of logging and mangrove coastal protections. Our fieldwork expanded upon these concepts as we learned the effects of contamination, boating wakes, and land development alongside reforestation practices such as soil usage, a nursery, seed gathering, and volunteer groups. A full facilitation guide along with debrief questions can be found in Appendix F.

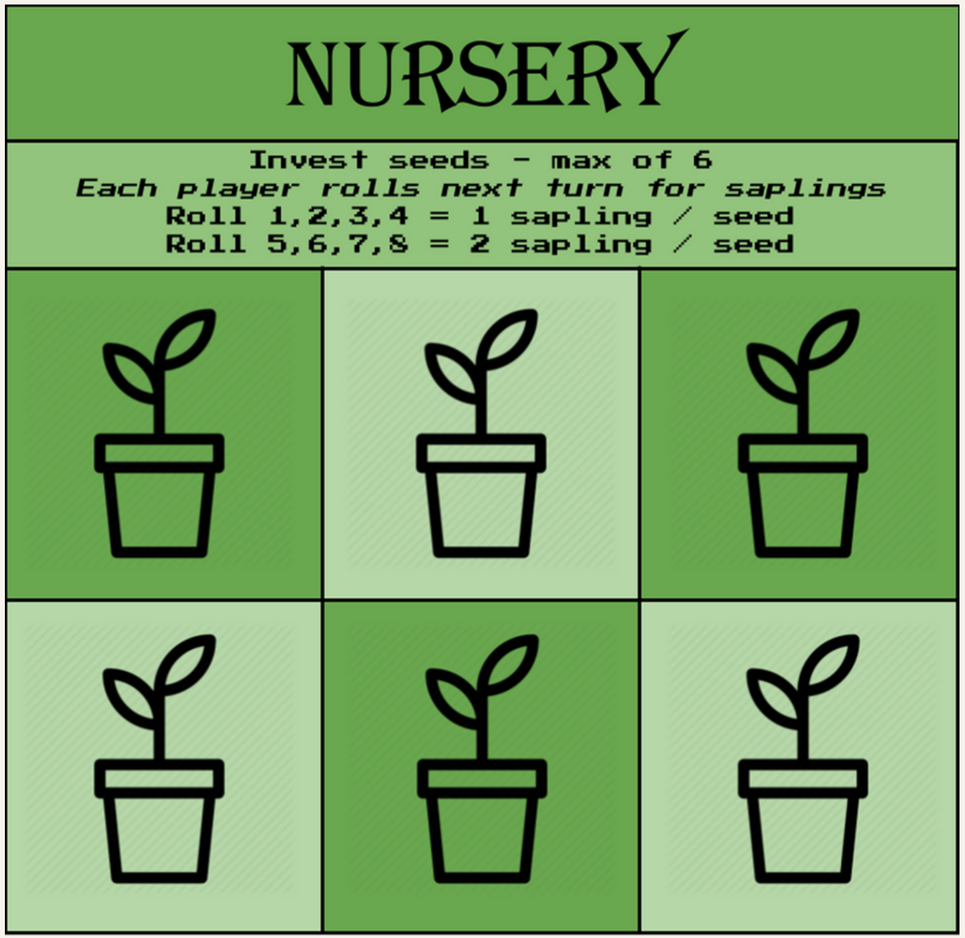


Figure 72. Nursery From 7 Day Mangrove Game

7-Day Mangrove Frameworks:

Criteria	Evaluation Framework
Development	
The game is visually appealing to players and easy to use.	Game Design: ● Was the design of cards, pieces, and game board visually pleasing? ● Were game pieces easy to handle? ● Were cards readable? ● Was the game board large enough? ● Was this game able to be played both indoors and outdoors?
Game Dynamics	
Players should easily understand the mechanics and choices they can make and strategize with each other based on these actions.	User Experience: ● Were the mechanics for the nursery, planting, growth, and events easy to understand? ● Were players aware of the actions and choices they could make? ● Were players strategizing together and communicating plans? ● Were players able to protect their community by the end of the turns allotted? ● Game balance: was the game too easy or too hard?
Players should be invested and engaged while playing the game.	Game Engagement: ● Were players actively engaged during gameplay? ● How frequently were players discussing with each other? ● Were users invested in the health and progress of their reforestation and mangroves? ● Were players frustrated or upset by any difficulties playing the game? ● Did players appear to be having fun while playing?
Educational Material	
Players will learn about threats to mangroves, the benefits they provide, the important aspects of a reforestation program, and the need to communicate and work together to protect the community.	Learning Outcomes: ● Types of mangroves ● Threats to mangroves ● How mangroves protect their community from storm surges ● How reforestation efforts can help promote mangrove development ● The importance of collaboration in mangrove reforestation ● Were players able to relate their own experiences or knowledge to the game? ● Was the game effective at simulating aspects of mangrove reforestation to the players?

First Round Testing: WPI Students

The first round of testing was with three WPI students, which allowed us to test for learning objectives with people who were not familiar with mangroves. We discovered that a key issue with the game design was that our thin paper tokens were susceptible to blowing away in the wind when the game was played outside. In the first revision, we backed the tokens with heavy cardstock to weigh them down.

Test players struggled with balancing gameplay and what were perceived to be convoluted mechanics. We shortened the number of turns it took to arrive at the end game condition, and we renamed the game to “7 Day Mangrove” as a result. The nursery mechanic had too many player actions which was confusing. We simplified that aspect of the game to focus on just seed investment, and we removed the spontaneous growth of mangroves. Event cards were also changed to make them larger threat that impact multiple zones, as players had a fully developed forest three turns before the storm hit.

Player responses to questions about learning objectives revealed they had learned the threats and importance of mangroves from gameplay but were confused as to the purpose of a nursery in mangrove reforestation. Edits to the nursery mechanic were made to focus on how it provides saplings for the reforestation effort.

Second Round Testing with Co-Researchers

We conducted a second test with two co-researchers and a community member, aged 23-26 years. We found that in this version gameplay and learning were both improved. Heavier pieces were no longer affected by the wind, so the game was more playable outdoors. Players suggested utilizing a magnetic strip for pieces to stick to, which would further improve playability.

In terms of user experience, players were still confused about the nursery upgrade mechanic, as they thought the seeds invested in this manner were the same as those invested for saplings. Further revisions scrapped this mechanic and restructured the nursery solely around investing seeds to receive saplings. A revised seed acquisition mechanic using a dice roll every turn meant players were able to plant earlier, and therefore were more engaged during the initial turns.

The shortened number of turns and increased difficulty also improved player engagement in the final turns. Players had to strategize more during the last turns, and only narrowly avoided defeat.

When asked how to improve the game, players indicated that a greater card variety and adding more mechanics for players to interact with events rather than just random dice rolls would make gameplay more interesting.

This ties into the key observation that during gameplay, players had begun to create what they called a head-canon, or story, around the events occurring through the game. For example, one player consistently drew the “logging” card, which could randomly destroy a line of mangroves on the board map. The player joked that his “logging squads” could sabotage the reforestation effort. Similarly, another player frequently drew positive event cards such as “volunteers” and “quality soil,” and players joked his “volunteer squads” were fighting the loggers. This unexpected imaginative head-canon allowed players to develop agency that increased player engagement and acquisition of learning outcomes.

During the debrief, players related the game to their own experiences relaying that “although we joked about logging squads and developers, this game reminded me of the stories my parents would tell me about how people used the mangroves for their own benefit. They would exploit the mangroves and leave it to the volunteers to clean them up.”

Evaluation of learning objectives also showed improvements. When asked to state the learning outcomes of the game was, players answered, “only the whole forest can stop the waves,” and “human activities affect the mangroves.” When asked what new information they learned from the game, one player answered they were not aware that red and black mangroves grow in different areas.

Unstable Mangroves Framework

The learning outcomes for “Unstable Mangroves” are to understand the man-made and ecological threats to mangroves in Piñones and how these can be combated. A full facilitation guide along with debrief questions can be found in Appendix G.

Criteria	Evaluation Framework
	Development
Create a colorful card game to show the threats on mangroves and how they can be counteracted.	Game Design ● Were the cards able to be understood? ● Was the wording on the cards big enough? ● Were the graphics on the cards matching the words? ● Were the cards big enough? ● Can this game be played outside in the wind?
	Game Dynamics
Users are able to read the upgrade and downgrade cards to learn about the positive and negative effects on mangroves.	User Experience ● Are users able to understand the rules? ● Were the cards clear to understand? ● Did the cards that match make sense? ● Did the graphic of the matching cards help the users? ● Did users have the correct table set up? ● Did users successfully complete the game? ● Did users have to ask a lot of questions to the facilitator?
The game environment is fun.	Game Engagement ● Was everyone involved in the competitive side of the game? ● Did users enjoy playing downgrade cards on others? ● Did users like the option of choosing their own types of seeds and mangroves? ● Did users appear to be having fun while playing?
	Educational Material
Players learn about the threats to mangroves and how they can be conducted. Players learn about positive factors the support the mangrove forest.	Learning Outcomes ● Threats to mangroves ● Benefits to mangroves ● How were the threats managed? ● What beneficial effects did players like the most? ● Have players ever witnessed any of the cards that were played? ● Were the graphics educational in how they demonstrated what everything looks like?

Initial testing of this game was conducted with a group of visitors at COPI and one of our advisors. The biggest concerns that arose during the game and debrief were about the sizing and visual aspects of the cards. Although this did not affect game enjoyment, it did affect user experience and the learning outcome that came from the game. Cards were originally a very small one inch by two inches and users were unable to easily read the wording on the bottom, which was necessary to understand the learning outcomes for the game.

We made the cards larger and added a larger font to support both user experience and learning. The final set of cards were 2-inches-by-3 inches and were in Spanish and English. The cards were printed in color and laminated. We also added rules for when a player wanted to use an upgrade, downgrade, or instant card, they would have to read the card out loud. This rule was implemented after we noticed that most of the players were not reading the cards but instead only looking at whether they were an upgrade, downgrade, or instant card. This negatively impacted the educational value of the game.

Reading the cards also helped with user experience. When players read their cards out loud, other players would be able to know what cards there are and what cards they need to know to play.

We re-tested the game at the Puerto Rico Walk of Fame Park with co-researchers and community members. Facilitators noticed that the competitive nature of this game allowed players to form alliances to try and win. This new addition to game play, which users chose on their own, drastically increased engagement levels. This was confirmed during the debrief session when players asked if they could play again with their new-found strategies.

In discussions about learning outcomes, players remarked that they spent time figuring out the sets of threats and benefits that worked together. They appeared to understand the importance of the benefits and why they were necessary to combat the set of threats. Learning outcomes were visible in the game and easy to understand.

Web-of-Life Frameworks

The Web-of-Life is an embodied game where participants describe specific relationships between organisms by passing around a ball of twine. The organisms in this game are all present in the Piñones mangrove forest. A full facilitation guide along with debrief questions can be found in Appendix H.

Criteria	Evaluation Framework
Development	
The game will be an engaging way to explore the ecological importance of mangroves in Piñones.	Game Design ● Was the ball of string easy to throw around the circle? ● Was the web made by the string easy to see? ● Were the component necklaces easy to see and read? ● Was the ball of string easily caught? ● Were people able to hold onto the string while they played?
Game Dynamics	
Players can toss a ball of twine to one another while explaining how different organism in an ecosystem interact with each other	User Experience ● Was there anything confusing or unclear about the game? ● Were the photos and words printed large enough for everyone to see?
Players will have fun while eliciting conversations about the importance of different organisms in an ecosystem	Game Engagement ● Did users appear to be having fun while playing? ● Were users engaged with the development of the web of life?

Educational Material	
Players will learn about the importance of mangroves and their role in providing a habitat for dozens of species of animals	Learning Outcomes ● The ecological importance of mangroves ● Were users able to understand why the ball of string was thrown to them? ● When were components taken out of the web was it clear to see how much would be affected? ● Which component had the easiest and the harvest time choosing where to throw the ball of string?

The initial prototype of the Web-of-Life game was tested with a group of 12 WPI students. Their feedback indicated that they did not understand why each part of the ecosystem was in the game. Some students struggled to connect organisms, such as insects and herons, to other organisms in the ecosystem. During the debrief, however, the facilitator asked probing questions about what would happen if there were no longer these birds or animals, helping players understand the importance that each component has in the entire ecosystem. Although we developed this game for younger audiences, we found that it can be effective at stimulating conversations around ecology and the importance of mangroves as habitats for different species for a wide range of audiences and ages.

Magnífico Tanque de Mangles

We designed, prototyped, and built the “Magnífico Tanque de Mangles” with Marcos Peñaloza, and our co-researchers Paola Rolon Diaz and Angel Berudez Gagot. The tank serves as an interactive exhibit at COPI with the purpose of teaching visitors about how mangroves protect coastal communities like Pinones.The tank was four feet long and a foot wide, built as an interactive demonstration and exhibition piece to simulate how mangroves can protect a community from strong waves.

We built the tank from scratch and incorporated fake mangroves. We initially planned to buy plastic model trees online, but we scrapped this idea as we discovered that shipping to Puerto Rico would likely take several weeks due to shipping delays. We also discovered that model trees were often created using craft wire. While this created adequate-looking mangrove models, due to the size and number of mangroves we needed, it was unrealistic to use craft wire because the models a long time to create. Finally, we decided to use readily available artificial plants made for aquariums. Because these artificial plants were quite small, we glued two layers of them onto a piece of plastic and spray-painted the bottom plant brown to appear more like the roots of the mangroves.

Along with iterations made to the design of the mangroves, we also iterated the mechanism used to create waves in the tank. Initially, the mechanism was going to be battery operated and adjustable with a speed dial. We decided, however, that if it were operated by hand, it would increase the interactive element of the design. When creating the wave mechanism, we wanted it to be possible for the frequency and size of the waves to be adjustable to show different types of waves. Plans to make the waves with an acrylic sheet hinged to the bottom of the tank were abandoned, as we did not want to screw holes into the tank to reduce the risk of leakages. Ultimately, we decided to make a plunger mechanism that was operated by pulling a string on a pulley as it would be the most practical and interactive way of creating waves.

The creation of the wave tank took longer than expected and we were not able to observe how community members interacted with it. We did, however, observe the attention that the tank drew while building it in COPI. We noticed interest from WPI students, COPI employees, and tourists visiting the building.

Chapter 6: Conclusion

Conclusion

Our project was centered on the Piñones mangrove forest in Loiza, Puerto Rico. The forest has cultural and historical relevance to the community while also providing numerous ecosystem services and protections against floods and hurricanes. Our immersive field research in the mangroves provided us with an understanding of the importance of mangroves to the local economy, ecology, and safety of Piñones. Our fieldwork and key informant interviews informed the development of four participatory games and a mangrove simulation wave tank for informal environmental educational.

Limitations

Our primary limitation was time. We found that we needed more time than we had expected to develop, prototype, test, and iterate on four participatory games and a wave tank. The games would benefit from further testing. Additionally, the creation of the simulation wave tank took longer than expected, largely due to difficulty acquiring materials. Due to limitations with materials and build time, we were only able to fully build the tank and its components along with a poster about the tank. We did not have anyone other than our sponsors and our team interact with the tank.

We also struggled with the language barrier. One of our co-sponsors, Marcos Peñaloza at COPI, only spoke Spanish and understood some English. Some of our team understood a little Spanish, but not enough to understand important scientific and cultural information. As one of our key informants, Marcos held the expertise on mangrove reforestation. Fortunately, we had the help of our co-researchers and other key informants to assist in the translation process. Fortunately, Marcos is an extraordinarily patient person and an exceptional educator. We learned a great deal from him even though we did not share a common language.

Recommendations

Continue Testing Games

We would like to recommend the continuation of testing and evaluation of our four participatory games. We were able to test user experience and game enjoyment, which have led to iterations that made the games more enjoyable, and evoke improved learning outcomes. However, further testing would improve the engagement and educational value of the games.

Test the Magnífico Tanque de Mangles

As we were unable to observe how people interact with the finished wave tank, we recommend that it be tested to determine its ease of use and if it reaches its intended learning outcome of teaching how mangroves prevent flooding in coastal communities. This can be done with visitors at COPI or anyone unfamiliar with the mechanism and purpose of the tank. The poster we designed to explain how to interact with the tank and its purpose should be alongside the tank. If the tank is determined to be confusing or lacking educational value, the poster should be edited to better facilitate interactions and learning outcomes.

Host Environmental Education Nights

We recommend that the wave tank and participatory games be played at environmental education nights for the community. This would allow our sponsors at COPI and LimPiaR to further develop learning outcomes and improve the games and simulation activities for the tank.

Develop Additional Educational Outreach Material

We recommend that the COPI team, experts at LimPiaR and future WPI students continue to create and implement Environmental Learning Outside of the Classroom educational outreach material. We advise using our games and simulations as a starting point to create more participatory games for and with the community.

Ethics

Our work in Piñones required us to understand and be aware of how racism and class structure has affected, and continues to affect, the Piñones community. Many community members in Piñones face discrimination and marginalization, and neighboring communities are often prioritized over Piñones. We want our work to convey the respect we have for this community and we have tried to be very careful in the way we speak and write about our project, in the physical work we did, and how we interacted with the community.

Reflections

When we arrived in Puerto Rico, we had a few ideas about what our project would be. In our first meeting at COPI we found out that our co-sponsor COPI was working on mangrove reforestation to mitigate floods and protect the canals for potential evacuation. In that moment, our project completely changed. We were challenged in ways we never imagined, spending days working in the hot and humid climate, waist deep in mud, planting mangroves to learn about their importance.

We were also challenged in many academic ways. Although we have strong technical backgrounds from our STEM education at WPI, we came into this project with little to no social science experience. We had to heavily rely on our advisors and co-sponsor LimPiaR to guide us through these processes. This humbled our team and allowed us to think deeper and more thoughtfully about everything that we created. The games and simulation we developed helped us grow as students, scientists, engineers, and educators. Most importantly, we developed lasting friendships and partnerships with everyone we worked with.

Concluding Remarks:

The Piñones mangroves have protected this community for hundreds of years. These trees have enhanced the community through benefits to the economy, natural beauty, and protective nature. There are numerous factors that have harmed these trees and the community for decades. The mangroves of Piñones will likely continue to face these threats, so we hope this project serves as a contribution to the efforts to expand environmental awareness about the importance of mangroves and how to help protect them.

Figure 73. Narrow Passage in Clemente Canal

Appendices

Appendix A - Our Team Introduction and Consent Script

Model Verbal Consent Language (In most cases, the essential elements of the following statements was conveyed verbally in conversational language to interviewees by students or co-researchers).

We are students from Worcester Polytechnic Institute (WPI) in the United States working in cooperation with LimPiaR and COPI to support their programmes and initiatives. To obtain different opinions regarding the development of mangrove educational materials in the Piñones community, we would like to ask you questions relevant to this topic. Your participation in this interview is completely voluntary, and it is important to us that you fully understand your rights throughout the interview process. For this, we have provided answers to some questions you might have. If you have any additional concerns, please do not hesitate to ask us.

How will my words, ideas and images be used?
Your answers to our questions will be used in reports presented to our sponsor and our university. Many of our reports and other project information will also be made publicly available, including through our project websites. We have a sample report for you to look at if you wish to have a deeper understanding of how we will use your responses, and our card includes our project website address. Copies of our reports will also be available for viewing from our co-researchers and/or project sponsors

How will my personal information be recorded and used?
We may record your personal information such as name and contact information for record keeping purposes, if you allow. This information will not be reported in any public manner without your permission. We will not distribute your information to any third party beyond our project sponsors and reports without your consent.

What if I change my mind and do not wish to participate in the interview?
Your participation in this interview is completely voluntary. You may end the interview process at any time. If we finish the interview and in the future you decide to not participate in the process, we will not use your answers. We will eliminate your information and interview from our records to ensure no information you presented can be used in our study or any other study.

What if I do not want to answer a particular question during the interview?
You can skip any question during the interview process at any time. You can do this for as many questions as you wish without consequence.

Who can I contact if I want further information regarding the project or the use of my interview responses?
If you have any questions or concerns regarding the project or your interview in particular, feel free to contact any of the contacts below:
Email: gr-pr_b21-pinones-mangroves@wpi.edu

Record-Keeping Permissions
All teams will keep a log of informed consent permissions granted containing the following information.

Model Written Consent Language: In the rare instance where written consent is warranted due to sensitive nature of material, students will adapt the following:

I, _____, agree to be interviewed by WPI students and/or co-researchers working in cooperation with LimPiaR and COPI on a project concerning the development of mangrove educational materials.

I have been informed of the confidentiality of information collected for this project and the anonymity of my participation. I have been given satisfactory answers to my inquiries concerning project procedures and other matters. I have been advised that I am free to withdraw my consent and stop my participation in the interview at any time.

Participant Signature: _____ Date: _____

Hello _ _ _ _ _ _ _. We are a group of students from Worcester, Massachusetts. We are attending Worcester Polytechnic Institute and doing a research project on developing mangrove educational materials in Piñones. We are currently working with LimPiar and COPI to help achieve this goal and were hoping we could ask you a few questions about your experiences and thoughts with mangroves in the community and educational games.

Our report looks to utilize local knowledge and expertise about mangrove maintenance and educational games to develop participatory games and a wave tank simulation demonstrating the importance of mangroves in Piñones. It will be available online after we finish writing it, and we can also email it to you if you wish.

Appendix B - Interview Questions

Questions for Marcos Peñaloza:

1. How long have you been working on the reforestation initiative?
2. How did you first get involved?
3. What is the motivation for this project?
4. How did you learn so much about mangroves?
5. Through personal experiences and/or research?
6. How have mangroves been rebuilt after Hurricane Maria? What did people learn from the process?
7. What have you done so far?
8. How have you been keeping track of all of your data?
9. What does the documentation for this initiative look like?
10. What things have had a negative impact on the mangroves?
11. How are mangroves important to the Pinones community specifically?
12. What improvements are still needed for the mangroves?
13. What are the threats to the mangroves in Pinones?
14. How have mangroves affected the community in the past?
15. What is currently happening with the government side of mangroves?
16. What agencies are involved? How do you work with these agencies?
17. How are you funding this initiative?
18. Have you applied for any grants?
19. What can we do to help you recieve funding and keep working on this initiative?
20. How is the community involved with the mangroves?
21. Would it be feasible to run outreach programs?
22. How do you see this being a community outreach program?
23. Can we work with the kids in the community? Revive the Super Hero Program?
24. Would participatory games be beneficial to show the importance of mangroves and how they are benefiting the community?
25. Who are the other community leaders that you work with?
26. Do you think we should also talk to them?
27. If yes: Could you give us a way to contact them so that we can set up a meeting?
28. Can you share with us photos of mangroves after Hurricanes Maria and Irma?
29. Is there any other information that you think would be beneficial for us to know?
30. Is there anything else that you would like to share with us?
31. Do you have any questions for us?
32. Ask if we can take a photo of them to put a name to a face in the report and thank them for being involved.

Questions for Auraluz Guzman:

1. How long have you been involved with LimPiar?
2. What has been your involvement in Pinones?
3. What is your relationship with COPI and Pinones?
4. What projects have you worked on?
5. How have you focused on community outreach and involvement?
6. What do you think are the best methods for community outreach based on your expertise?
7. How is environmental education important to LimPiaR's goals?
8. How have you worked with kids in the past to spread environmental education? What methods did you use to share this information?
9. Would these kids benefit from learning about mangrove reforestation?
10. How have you used games to educate communities in the past?
11. What other ways have you been able to interact with and engage community members?
12. Have you used forms such as pamphlets or videos in the past? Have they been successful?
13. Is there any other information that you think would be beneficial for us to know?
14. Is there anything else that you would like to share with us?
15. Do you have any questions for us?
16. Ask if we can take a photo of them to put a name to a face in the report and thank them for being involved.

Questions for Paola Rolon Diez:

1. How long have you lived in the pinones community?
2. How did you get started as a co researcher for our project?
3. What are your connections with the community?
4. Have you been involved with COPI and LimPiaR before?
5. How have you been involved?
6. What have you been doing in efforts for mangrove restoration since the project has started?
7. How do you interact with the mangroves in Pinones?
8. How has this project affected you?
9. Can you tell us about the importance of this project to you and your community?
10. Do you have an idea about how to get other community members involved with this project?
11. Where could we meet with other community members to show them the importance of this project and its impact?
12. We noticed a truck broadcasting events to the community, would this be a good way of getting a message out to the community, if so, how might we do this?
13. What kind of games do you like to engage in?
14. Either now or from your youth?
15. Are there any popular games in Pinones that you know of?
16. Is there any other information that you think would be beneficial for us to know?
17. Is there anything else that you would like to share with us?
18. Do you have any questions for us?
19. Ask if we can take a photo of them to put a name to a face in the report and thank them for being involved.

Questions for Nuria Escalera:

1. How long have you lived in this community?
2. Can you tell us about the changes both positive and negative that you have seen since you have lived here?
3. With your involvement in the community, can you let us know how the environmental regulations have affected how the community runs?
4. How long have you been involved with COPI?
5. What have you done with COPI?
6. How has your involvement in COPI helped the community?
7. What are you currently working on with COPI?
8. What was mangrove education like while you have lived here?
9. How has your experience been with mangrove restoration?
10. Do you have any ideas about community outreach to spread information about mangrove restoration?
11. How would you suggest people who can be more involved with this?
12. Would the churches in the community be willing to spread information about this issue? Is there a way to spread information?
13. Is there any other information that you think would be beneficial for us to know?
14. Is there anything else that you would like to share with us?
15. Do you have any questions for us?
16. Ask if we can take a photo of them to put a name to a face in the report and thank them for being involved.

Appendix C – Notes from Field Research

Schedule of Field Research

Date	Location	Activity
10/28	Clemente Canal	Planting Red Mangroves
11/2	Peninsula of the Fishermen	Planting Red Mangroves
11/4	Peninsula of the Fishermen	Collecting White Mangrove seeds.
11/4	Boardwalk	Spreading white mangrove seeds in new zones. Finding a new zone and clearing it while also spreading seeds.
11/9	Boardwalk	Planting Red Mangroves
11/11	Clemente Canal	Kayaking through escape routes

Appendix C1 – Notes from October 28, 2021

Attendance: Marcos, Nuria, Marcos Jr., Orlando, and Miguel (2 COPI employees)
Location: Clemente Canal
Date: 10/28 from 8:30 AM-1:00 PM

Today was the first day that we went into the mangrove forest. This started with us taking an Uber to COPI where Nuria picked us up and drove us into the Piñones community. During this, she pointed out her home(and her dog Pocket Polly) and other members of the community. We parked by a dock where we met up with Marcos, Orlando, and Miguel. Then we took three two-seater kayaks out on the dock over to the Piñones along with two crates of mangrove saplings and a cooler of water. Then we got onto the water and started to explore the zones where the mangroves are planted. Here we learned more about how mangroves are planted and the history behind the trees. We asked many questions to Nuria and Marcos. Later on Marcos' son, Marcos Jr., joined us and helped be another translator. Once we had planted all of the trees, Marcos and Nuria drove us over to the Piñones Forest Nature Reserve. Here we were able to wash off all of the mud and get changed as well.
Since we were in kayaks and on the water, we were unable to take notes. So below we have written up what we learned while we were there from memory.

Notes from information mentioned by Marcos:

- He pointed out a zone where almost all the mangrove sprouts had died (only 4 were left and not super healthy). We asked what caused them to die and he explained that excessive rainwater had diluted the area there and reduced the salinity to a level below that which mangroves can grow healthily in. Due to increased rainfall and during heavy rains (aka storms), alot of freshwater is added into the mangrove habitats which dilutes the salinity and can kill off mangroves.
- Nuria Pointed out places where charcoal was made, the ground was noticeably charred and the areas were located a bit into the trail so they were out of the way. There is still a risk even when making charcoal out in the woods as smoke from the fires can rise and draw attention.

○ Furthemore while kayaking we learned that the charcoal was only made from dead mangrove branches (people were not cutting down/using living mangroves). The drier dead wood is better for charcoal making and there is the added benefit that charcoal makers would clean/maintain the mangroves by removing dead plants. Without this maintenance the excessive dead mangroves can start to clog up the rivers as they are broken down by termites and decay into soil. We noted many areas where there was a lot of dead wood and sometimes Orlando and Pabo had to use a chainsaw to break apart large logs and clear out the debris so that new mangroves could be planted in that zone.

● Some saplings were planted with the plastic bottle still on and the cap removed. This was to make sure the roots spread downward rather than to the sides. While the plants grew they would carry the bottle out of the soil allowing for it to be removed. The locations of these bottles were recorded so that they may be removed a month or 2 later after the mangrove has grown.

● “This is hard work but it is necessary.” - Marcos. No one else is doing the work needed to maintain and restore these trees so even though the forest is smelly and muddy and needs a lot of labor, it is important to help protect the community.

○ Even during the high tides where it becomes treacherous and the water can be up to your waist or higher.

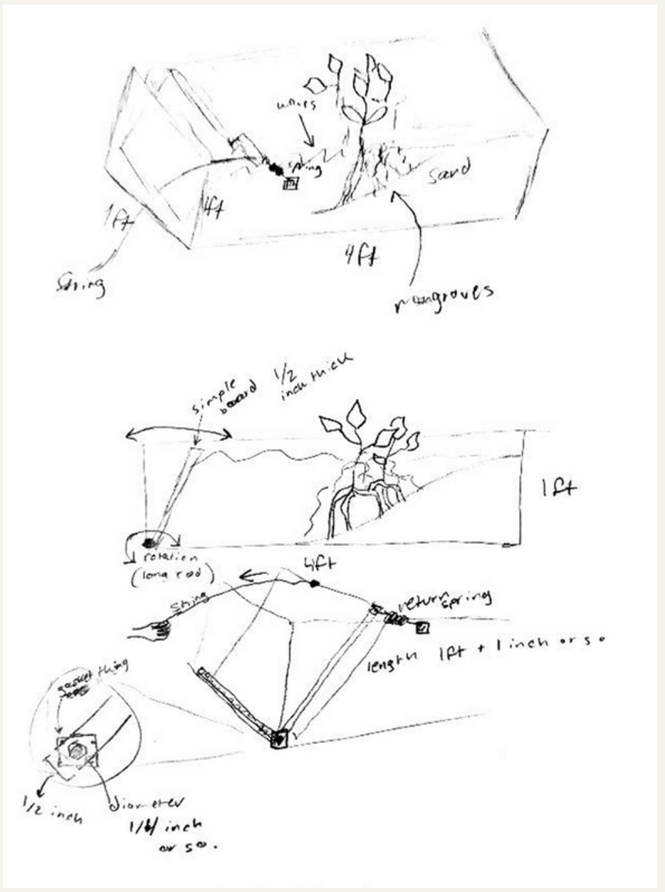
○ Marcos mentioned some benefits the mangroves provide such as flooding protection.

● We will likely come to a different location, that is more walkable and near the Department of Natural Resources, details will be finalized on Monday

● They do this everyday for up to eight hours. There only seem to be four people directly involved: Marcos, Orlando, Miguel, and Lenny.

● Today we only planted red mangroves but we also got to see where the white mangroves are planted. We were told that we will most likely end up working with the white mangroves since those do have better conditions to work in.

Appendix D- Designs for Wave Tank



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