WPI Puerto Rico Project Center

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A Feasibility Assessment of a Carbon Credit Program in Punta Cabullones

An Interactive Qualifying Project Report Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

Para La Naturaleza (PLN), an environmental nonprofit, plans to start a carbon crediting program to fund their projects throughout Puerto Rico. Our project conducted a feasibility assessment for PLN using a planned mangrove reforestation project in the Punta Cabullones Natural Protected Area as a case study. We investigated best practices from mangrove monitoring plans, determined the steps to become carbon credit certified, and estimated the organizational and economic feasibility of participating in carbon crediting. Though there are some concerns with Verra and the market as a whole, we determined the steps to create and maintain a carbon crediting project and concluded that the program is profitable.

Executive Summary

Para la Naturaleza (PLN) is an environmental organization that is working towards their goal of protecting 33% of ecologically valuable land in Puerto Rico by 2033. Carbon crediting is a supporting incentive for organizations to sequester carbon and help fund their projects. PLN wants to implement a carbon crediting program with Verra, the world's largest distributor of carbon credits. The goal of this project was to evaluate the carbon-sequestering potential of a mangrove reforestation plan at Punta Cabullones Natural Protected Area and assess the economic benefits of participating in a carbon credit program. This was accomplished through the following objectives:

1. Investigate best practices to monitor health and carbon sequestering ability of mangrove forests.
2. Determine the requirements to establish and manage a carbon credit certified area.
3. Evaluate carbon credit availability and profitability for the mangrove forest in Punta Cabullones.

Background

Globally, humans emit approximately 40 billion tonnes of carbon per year, increasing the concentration of carbon in the atmosphere by 50% since the Industrial Revolution (Fang et al., 2011; Ritchie & Roser, 2024). This increase is causing global issues such as global warming, ocean acidification, and more severe natural disasters (Lindsey, 2023; US EPA, 2016). These effects especially harm islands in the Caribbean. As a small island in the Caribbean, Puerto Rico takes the brunt of stronger hurricanes, and many coastal communities are at risk of being submerged from sea level rise. Due to the worsening debt crisis, Puerto Rico has limited resources to prepare for and respond to climate related disasters.

Carbon sequestration can mitigate carbon emissions and slow the progression of climate change. Carbon sequestration is the removal of carbon from the atmosphere through technological or environmental capturing methods. Nature-based Solutions are a popular emerging carbon sequestration method in which organizations facilitate the growth of environments to increase nature's carbon sequestering potential, along with its other environmental benefits.

Mangroves are a promising Nature-based Solution. They provide a variety of ecological benefits, such as preventing soil erosion, mitigating the effects of sea level rise, acting as a storm buffer against hurricanes, and providing habitats for thousands of species. Mangroves sequester carbon at a higher rate than other tree species, making their reforestation a promising carbon sequestering opportunity. Despite the benefits that mangroves provide, they are at risk from climate change and human deforestation, increasing the importance of conservation and reforestation efforts.

One Natural Protected Area that has been identified as a potential asset for a carbon crediting program is a wetland in the south called Punta Cabullones (Figure A). PLN is currently seeking to implement a carbon crediting program in Punta Cabullones based on their 2021 La Esperanza / Punta Cabullones Reforestation Plan, which plants a significant number of mangroves. Carbon credits are a method for organizations to generate funding through reducing carbon in the atmosphere. For every tonne of carbon dioxide sequestered or prevented from being emitted, an accredited organization generates one carbon credit (Ollendyke, 2023). This credit can then be sold to carbon emitting companies for them to become ‘carbon neutral’ (Figure B).

Figure A: Map of Punta Cabullones (2021 La Esperanza / Punta Cabullones Reforestation Plan)

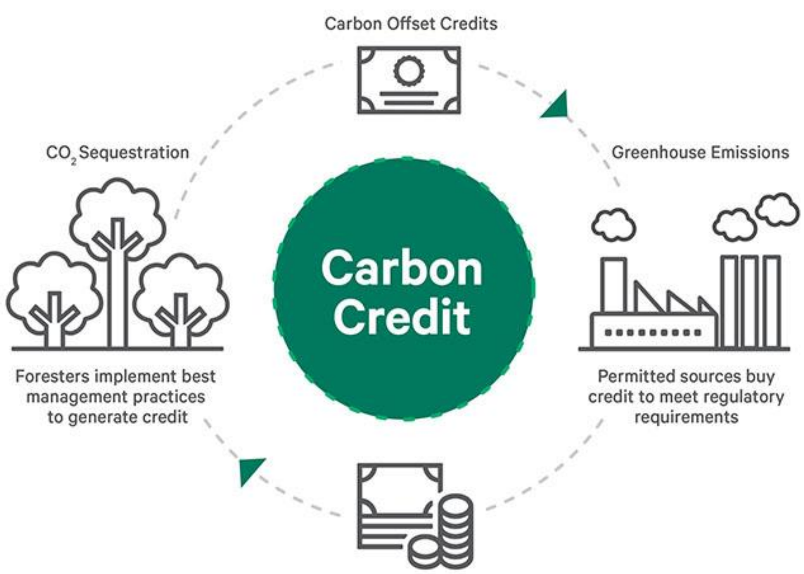

Figure B: The carbon credit process (NEWGEN)

Methodology

Our methodology consisted of conducting interviews with experts, reviewing the Verra carbon crediting system, and calculating the benefits of implementing the 2021 Reforestation Plan.

To understand experts’ perspective, we conducted twelve semi-structured interviews with PLN staff members, other environmental professionals, and former Verra staff. Our group asked questions about mangrove monitoring practices, assessment of mangrove health, and the use of remote sensing or other applications to track mangrove progress. The team gained perspective on the monitoring process by visiting La Parguera, a similar PLN Natural Protected Area that has mangrove growth, and taking the same measurements that volunteers would use to measure mangrove health and condition (Figure C). We also interviewed the same twelve experts about the requirements to certify an area to generate carbon credits, and the challenges that commonly arise in the process as well as mangrove's use in carbon sequestration programs. We thoroughly reviewed Verra's website to determine program resources, validation and verification, and calculations.

Figure C: Mangrove monitoring at La Parguera

We calculated the profitability of implementing the Reforestation Plan by first determining the sequestration rate through multiplying the sequestration rate per area by the hectares of land being reforested. We calculated the profitability of carbon credits from Punta Cabullones by using the projected carbon sequestration rate and converting it into average annual carbon credits, multiplying the price per carbon credit, and subtracting the estimated costs. We compiled data from the Reforestation Plan and the PLN-Site-Based-Project-Feasibility tool spreadsheet.

Results

Our research found that implementing the 2021 La Esperanza / Punta Cabullones Reforestation plan would be beneficial to PLN in terms of generating a profit and sequestering carbon. Out of the 40 active Verra methods, we found VM0033 Tidal Wetlands and Seagrass Restoration to be most relevant to Punta Cabullones for starting a carbon crediting program. The main requirements outlined in Verra's methodology are establishing a baseline, setting up a consistent monitoring schedule, and getting audited. We developed the following four steps to meet Verra's guidelines for any PLN projects while using Punta Cabullones as a case study:

1. Assess the Benefits of Implementing Carbon Crediting
2. Establish a Project with Verra
3. Evaluate and Adapt Monitoring Standards
4. Conduct Verification for Carbon Credits

Punta Cabullones has the potential to sequester 990 tonnes of carbon yearly through reforestation. Additionally, PLN is projected to profit an estimated $15,500 annually by participating in the Verra carbon offsetting program. The predicted costs, as estimated by the PLN-Site-Based-Project-Feasibility-Tool, for implementing the Reforestation Plan as a Verified Carbon Standard (VCS) project will be on average $27,000 annually. Although the price of carbon credits fluctuates with the market between about $40 - $80 per carbon credit, using an average price for blue carbon of $45 per credit, PLN will earn an average revenue of $42,500 annually over the 20-year project period.

PLN is in the process of becoming an accredited VCS organization. Once accredited, they can establish projects with Verra, which requires creating a detailed project description, including baseline carbon sequestration calculations to evaluate project progress. In addition, projects must select the most appropriate Verra Methodology for the given environment. Wetland Restoration and Conservation aligns best with the mangrove reforestation of Punta Cabullones. Therefore, we identified Verra's VM0033 Tidal Wetlands and Seagrass Restoration as the most relevant methodology for Punta Cabullones. After project design is complete, it is eligible for validation, the first audit, in which the project design and carbon removal estimates are evaluated to ensure they follow VCS standards and use reasonable assumptions and methods.

PLN does not currently conduct monitoring in Punta Cabullones due to its remoteness and occasional inaccessibility. To successfully implement the Reforestation Plan and earn carbon credits, PLN will have to establish a more rigorous monitoring program, which will help them meet the internal goal of an 80% survival rate. Interviews with various experts indicated that the most helpful tools for successful monitoring are the application Survey123 and permanent parcels, which are sample plots of the overall environment. Monitoring at frequent intervals immediately after planting allows for replanting to occur as needed. After significant time has passed, frequency can decrease to optimize the use of resources.

Five years after the implementation of the Reforestation Plan, the project will be eligible for verification, the process by which PLN can be awarded carbon credits upon proof of significant carbon sequestration. The selected Verra Methodology describes specific process details, beginning with internal evaluations, followed by an audit conducted by a third-party auditor. After the first audit, verification can occur at any frequency that PLN desires as long as significant change can be documented. Verification typically occurs every five years and should be no more frequent than once per year. Finally, carbon credits do not need to be sold all at once, allowing organizations to sell credits during favorable market fluctuations, and induce revenue as needed without conducting verification again.

Considerations for a Carbon Credit Project

As with any new project, it is important to consider all the factors that may affect the implementation and success of the program. With this feasibility assessment of a carbon credit program in Punta Cabullones, there are many aspects to analyze in terms of the calculations done, Verra's recent controversies, and drawbacks within the carbon credit market as a whole.

The calculations for Punta Cabullones suffer from unpredictable input metrics. Values such as the inflation rate, price of carbon credits, survival rate of trees, and others are difficult to determine with certainty. Some input metrics are highly variable depending on whether PLN uses volunteers or paid employees to implement the carbon crediting program. Using volunteers, the price of supervising staff, transportation, and potential stipends would alter the cost. Additionally, if a disaster occurs, the health of the newly reforested mangroves may be affected, decreasing the amount of carbon they may be able to sequester. Fewer carbon credits would be generated, and projects may suffer a financial loss. The cost of carbon credits also depends on who is buying them and what they are willing to pay for it, which can alter the price per carbon credit by almost $40 across various types. Though these calculations are rough estimates, they offer a general assessment to guide PLN's decision to participate in a carbon credit program.

Another important factor to consider is the organizational size. Verra is designed to work with larger projects that will earn a substantial quantity of carbon credits, thus justifying the high annual subscription costs. Simply maintaining a Verra project, regardless of size, can cost over $17,500 initially, and $5,000 each year. Projects comprising 1,500 hectares or more are generally more successful, and the cost of carbon credit programs are non-linear relative to size, such that smaller projects cost much more than larger ones on a per hectare basis. Combining several similar locations and projects into one has the potential to save money, but must be done carefully, as it also has the potential to create an overly complicated project.

Many experts have also noted that there may be aspects of greenwashing within the carbon credit market. The main issues that arise with companies buying carbon credits include double counting credits, using credits in lieu of reducing emissions, and credits not representing actual carbon emissions being removed (Galey, 2022; Raji, 2023; Romm & Schendler, 2023). Some sources also argue that carbon credits do not always represent a tonne of carbon removed from the atmosphere. In 2023, The Guardian, an independent British paper, published an article claiming that Verra overestimated potential deforestation, thus inflating the carbon value of the issued credits. Although Verra refuted these claims and the specific program targeted is irrelevant to this project, it is important to keep in mind the implications of this controversy.

Conclusion

We showed that, through the Verra VCS program, PLN could cover the costs of implementing the reforestation program and additionally make an estimated average annual profit of $15,500 over 20 years, helping to fund other PLN projects. Despite the controversy around carbon crediting, the positive impacts for an environmental organization such as PLN outweigh potential risks. As carbon crediting in Punta Cabullones is shown to be favorable through this study, a further investigation of the benefits of carbon crediting for other reforestation plans is warranted.

Acknowledgements

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Introduction

Globally, humans released nearly 40 billion tonnes of carbon dioxide in 2022 (Ritchie & Roser, 2024). Carbon dioxide emissions, along with other greenhouse gases, have been steadily rising since the late 1700s (Fang et al., 2011). The carbon, trapped in the atmosphere, retains and radiates heat, contributing to a rise in global temperatures (Lindsey, 2023). As a small island in the Caribbean, Puerto Rico is especially vulnerable to the effects of climate change. Sea level rise threatens to submerge coastal communities and hurricanes Irma and Maria caused $68 billion in damage in 2017 (Economic Commission for Latin America and the Caribbean, 2022; Santos-Burgoa et al., 2018). Many Puerto Rican communities are also reliant on the coast for resources such as fish and crabs, so the destruction of this environment threatens their livelihood (Gattuso et al., 2013). Mangroves, while they make up 1% of tropical forests, sequester approximately 13.5 billion tonnes of carbon per year (Alongi, 2012; Lindsey, 2023). As a result, they are an effective mitigation and adaptation measure. One entity in Puerto Rico working to reforest mangroves is Para La Naturaleza, a nonprofit organization.

PLN has done a variety of tree planting across the island, including mangrove reforestation during Mangleton in 2021. Mangleton was a one-day planting marathon in Hacienda La Esperanza, one of the Natural Protected Areas they manage. In addition to reforestation events, PLN also manages and maintains several Natural Protected Areas with the goal of conserving and protecting Puerto Rico's natural environment. After acquiring Punta Cabullones, a Natural Protected Area in the south of Puerto Rico, PLN created the 2021 La Esperanza / Punta Cabullones Reforestation Plan for mangroves and other vegetation. Reforesting mangroves, which currently make up 15% of the 671 acres of protected area, would provide crucial benefits, such as buffering storms for the nearby city of Ponce, reducing soil erosion, and capturing carbon dioxide from the atmosphere (Para la Naturaleza, 2014). Since PLN is participating in these carbon-capturing efforts, they are eligible to generate carbon credits. These carbon credits can be sold to companies who want to offset their carbon emissions, thus funding PLN's other environmental endeavors.

Our project evaluated the carbon-sequestering potential of a mangrove reforestation plan at Punta Cabullones and assessed the economic benefits of participating in a carbon credit program. Our objectives were to investigate the best practices from local mangrove monitoring plans to inform carbon-sequestering endeavors, determine the steps to become carbon credit certified, and evaluate the extent of carbon credit availability and profitability in Punta Cabullones.

In the following section, we discuss carbon emissions and the effects of climate change on Puerto Rico. We then shift to carbon sequestration and credit programs, reviewing Nature-based Solutions to mitigate climate change effects. We narrow our focus to mangroves as a Nature-based Solution, analyzing their benefits and vulnerabilities and how they may be assessed for restoration and conservation. We also briefly overview Punta Cabullones and Para La Naturaleza. Our methodology synthesizes a plan to show the viability and benefits of a carbon credits program using semi-structured interviews with PLN staff and pertinent researchers, the PLN Site-Based-Project-Feasibility-Tool, and the 2021 Restoration Plan to estimate the amount of current and future carbon sequestration potential in Punta Cabullones and developing informational material from our compiled data to inform PLN staff.

Background

2.1. Carbon Emissions and Climate Effects on Puerto Rico

The rate of carbon emissions and temperature globally have spiked dramatically in the last few centuries, mainly due to human activities. Burning fossil fuel for transportation, production plants, and generating electricity all increased exponentially during and after the Industrial Revolution (US EPA, 2021). Fossil fuel use produced elevated levels of carbon dioxide, a greenhouse gas that absorbs and radiates heat, as shown in Figure 1, and contributed to climate change. In 2022, the amount of carbon dioxide emitted from fossil fuels grew to 37.15 billion tonnes annually (Ritchie & Roser, 2024). Globally, the amount of atmospheric carbon dioxide has increased by 50 percent from 284 ppm before the Industrial Revolution in the late 18th century to 424 ppm in 2023 (Fang et al., 2011; Lindsey, 2023). The more carbon dioxide that is added into the atmosphere, the more the Earth's temperature keeps rising, resulting in global warming (Lindsey, 2023). The global average temperature has risen by 0.74ºC in the last century, as shown in Figure 2 (Fang et al., 2011). Greatly increasing carbon emissions and temperature have worsened climate change worldwide.

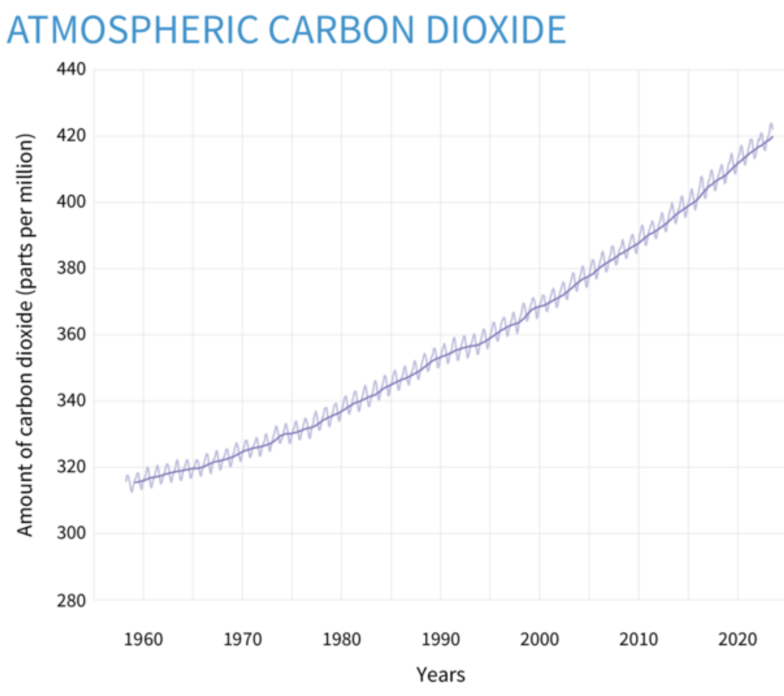

Figure 1: Record of Atmospheric Carbon Dioxide Level
Record of atmospheric carbon dioxide levels as observed from Mauna Loa Observatory in Hawaii (1958-2023). The overall rise in levels is driven primarily by anthropogenic activities (Lindsey, 2023).

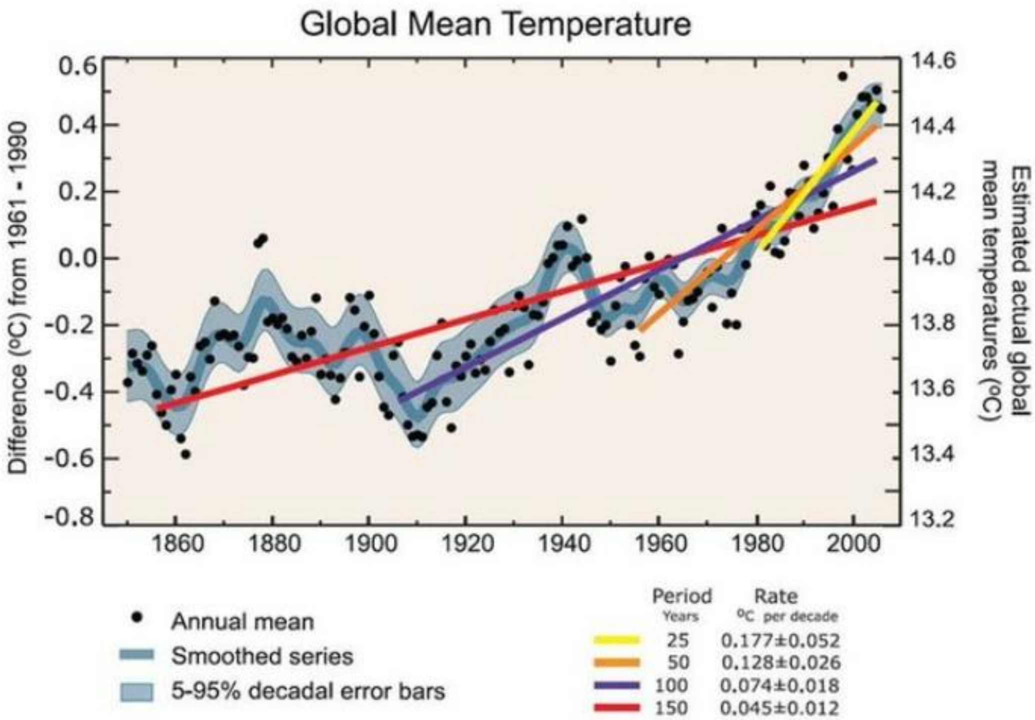

Figure 2: Variations in average global temperature 1850-2005.
Each color represents a warming rate for a different period of recent years (i.e.: red represents the last 150 years and yellow represents the last 25 years). This graph highlights the significant increase in warming rate in the last 100 years (Fang et al., 2011).

In addition to rising temperatures, the increased carbon dioxide in the atmosphere gets dissolved into the ocean, creating devastating effects for marine life. The ocean absorbs about a third of the CO_2 that is released to the atmosphere, accelerating the effects of climate change (Fisheries, 2021). Stored carbon dioxide reacts with water, producing carbonic acid which lowers the ocean's pH and results in ocean acidification (Lindsey, 2023). Ocean acidification is harmful to a variety of ocean and coastal life like calcifying organisms, coral reefs, and mangroves (Enzor et al., 2018; NOAA Coral Reef Conservation Program, n.d.). The lowered pH dissolves exoskeletons and increases calcifications, bleaches coral, and creates uninhabitable ecosystems for these plants and animals to thrive.

The effects of carbon-driven climate change are particularly harmful to small islands, such as those in the Caribbean. The size, geography, and remoteness of Puerto Rico increases vulnerability to climate change and reduces its ability to recover from climate related events (Mycoo & Donovan, 2017). According to NOAA, nearly 67% of Puerto Rico's population lives in coastal areas, which are more susceptible to damage caused by storms and changes in ocean conditions. Rising ocean surface temperatures result in higher humidity levels and higher energy tropical storms, leading to more severe damage (US EPA, 2016). In 2017, Hurricane Irma and Hurricane Maria hit Puerto Rico, costing $68 billion dollars and approximately 3,000 lives (Economic Commission for Latin America and the Caribbean, 2022; Santos-Burgoa et al., 2018). Coastal areas, and particularly islands, are subject to Sea Level Rise (SLR), as global warming results in the thermal expansion of water and glacial ice melting into the sea. In Puerto Rico, sea level is projected to increase by 1.1 to 6.8 feet before the year 2100 depending on severity, as shown below in Figure 3 (*Flooding Analysis Tool*, n.d). SLR causes the coastal environment to move inland, diminishing the dry forest area and degrading the habitat for many species (Gould et al., 2022).

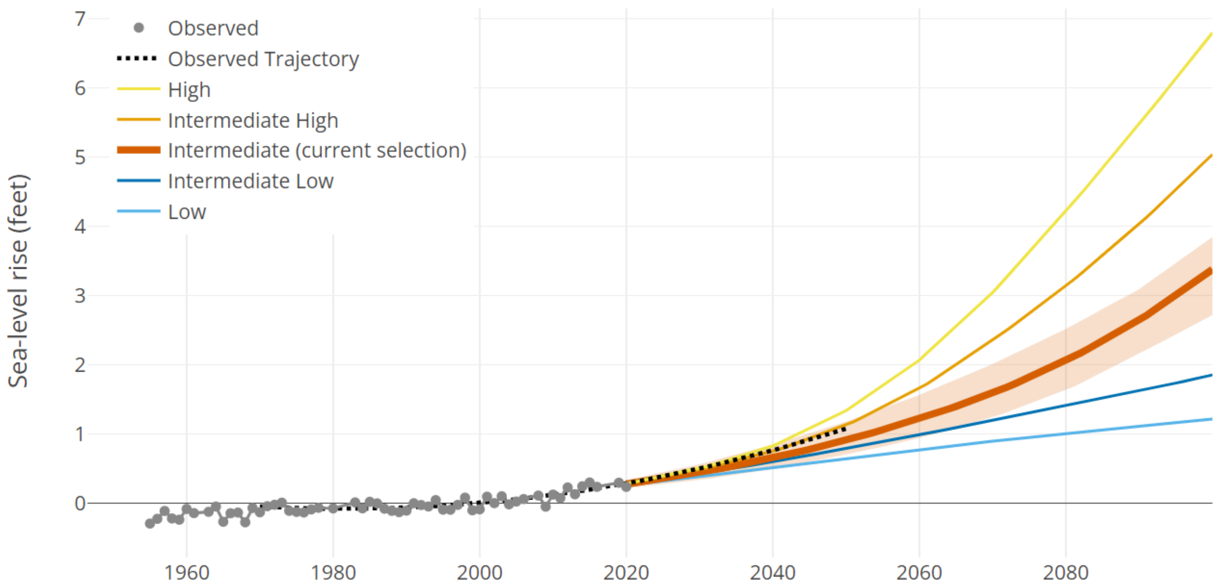

Figure 3: Sea level change over time scenarios in Magueyes Island, La Parguera
The graph illustrates sea level change projections up to the year 2100. Magueyes Island, La Parguera, Lajas, is roughly 30 miles west of Punta Cabullones. The graph represents different SLR scenarios, ranging from 1.2 feet to 6.8 feet (Flooding Analysis Tool, n.d.).

As an island, Puerto Rico will face the most severe consequences of climate change in the near future, impacting historically marginalized communities to an even greater extent. Due to the worsening debt crisis, Puerto Rico has limited resources to prepare for and respond to climate related disasters. As much as 55% of buildings have been constructed without an engineer or architect, building codes, building permit, or land title, meaning that they are more likely to be affected by flooding, storm damage, or SLR (García & Hernandez, 2023). Coastlines will recede, leaving some areas uninhabitable and causing coastal communities to relocate. Additionally, ocean acidification can harm many low-income communities that rely on local marine food sources, such as crabs or fish for economic support and survival (Gattuso et al., 2013). Despite producing less than 1% of the United States' greenhouse gas emissions, climate change is an inevitable threat to Puerto Rico (Gould et al., 2022). However, steps can be taken to reduce climate threats by mitigating anthropogenic carbon emissions.

2.2. Carbon Sequestration and Carbon Credit Programs

The Intergovernmental Panel on Climate Change (IPCC), in 2018, identified carbon sequestration technologies as one of the ways that the amount of carbon dioxide emissions can be limited (IPCC, 2018). Carbon sequestration is the process of capturing, securing, and storing CO_2 from the atmosphere, stabilizing the carbon in both solid and dissolved forms (Clear Center, 2019). The ocean and forests are both natural methods to capture carbon, each absorbing about 25% of carbon dioxide emitted from human activities annually. The soil, grasslands, and geological formations are other biological ways to sequester carbon. Carbon dioxide can be captured directly from the industrial facilities in which it is produced by using direct air capture or engineered molecules (Office of Science, n.d.; "What Is Carbon Sequestration and How Does It Work?", 2019). Carbon sequestration is important to reduce the effects of global warming, ocean acidification, and overall climate change.

Carbon credit programs have been developed as a market-based solution to fund carbon sequestering activities. Carbon credits are a way for entities to counteract their own carbon emissions by purchasing a "credit" that corresponds with a carbon reducing action done by a carbon credit seller (Thompson & Miranda, 2021). One carbon credit is equivalent to the emission of one metric ton of carbon (Ollendyke, 2023). For example, an airline could buy credits from an agriculture company that is implementing more carbon friendly practices. This arrangement is beneficial for both parties, as the purchaser can offset their emissions in a cost-effective manner, and the seller can receive additional capital to support environmental efforts. To be eligible to sell carbon credits, organizations can choose from a variety of sequestering methods. Although the market is projected to be worth $50 billion in 2030, many people question the validity of the system (Blaufelder et al., 2021). Critics argue that a carbon credit program does not actually prevent greenhouse gases from being emitted and allows companies to present an ecofriendly façade (Thompson & Miranda, 2021).

As carbon emissions continue to degrade natural and human ecosystems, researchers found ways to mitigate the effects and restore the environment, many of which can be used in carbon crediting programs. Engineered options such as onsite powerplant sequestration are being explored as methods to reduce carbon emissions; however, these options are typically expensive and difficult to implement (Hezrog & Golomb, 2004). A more versatile option, growing in popularity, is Nature-based Solutions (NbS). A NbS strengthens the existing environment, allowing it to mitigate effects of climate change naturally and is typically less costly than a man-made solution (Soanes et al., 2023).

2.3. Mangroves as a Nature-based Solution

As an NbS, Mangrove forests have a variety of ecological benefits. They mitigate flooding and SLR, act as a habitat for thousands of species, provide food, and prevent soil erosion (Barbier, 2016; Sunkur et al., 2023; *Why Mangroves Matter*, n.d.). Mangrove forests mitigate the effects of both short-term natural disasters and long-term climate effects. They also act as a storm buffer and lessen hurricane damage, as shown in Figure 4. As storm surges rise, the waves passing through the complex root system lose energy and shrink in size by the time they reach settlements further inland, reducing flooding (Sunkur et al., 2023). The density of mangrove canopies buffers winds, reducing the damage communities face during severe storms (Das & Crépin, 2013). Furthermore, as shown below in Figure 5, mangrove trees reduce erosion, protecting vulnerable coastlines against SLR (Sunkur et al., 2023).

Figure 4: Mangroves provide a barrier between storm surges and inland structures
Mangrove forests, depending on size, density, and age, can reduce the effects of storm surges and protect coastal communities (Sunkur et al., 2023).

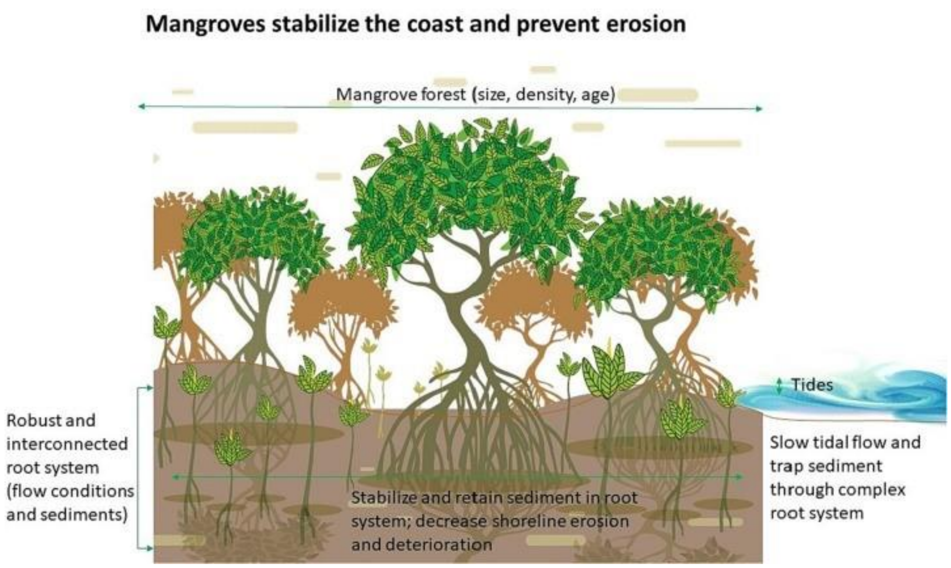

Figure 5: Mangrove roots reduce erosion by retaining sediment
Reduced erosion stabilizes coastlines and greatly slows the rate at which ecosystems are destroyed by rising sea levels. (Sunkur et al., 2023).

In addition to other benefits, mangrove forests sequester a significant portion of global carbon emissions. Although mangroves comprise less than 1% of tropical forests, they sequester an approximate 13 billion tonnes of carbon each year, ten times the rate of mature tropic forests annually (Alongi 2012; Kumagai et al., 2020). Per unit of area, mangroves store three to five times as much carbon in the soil (*Coastal Blue Carbon*, n.d; Locatelli et al., 2014). Due to high productivity and carbon flux rates, mangroves can store more organic carbon in sediment than in biomass, allowing for greater underground sequestration (Alongi, 2012; Donato et al., 2011; Meng et al., 2021). Mangrove deforestation not only reduces carbon mitigation capabilities and releases carbon back into the atmosphere but also hinders these benefits. According to Locatelli et al. (2014), tropical forest deforestation may account for 8 – 20 % of anthropogenic CO_2 emissions.

Despite the climate mitigation and adaptation benefits mangroves provide, climate change and other human factors put these trees at risk. Literature shows that most mangroves will be lost to SLR in the next 100 years (Lovelock, 2020; Para la Naturaleza, 2014; Saintilan et al., 2020). Shoreline erosion accounts for 27% of mangrove loss globally since 2000, and extreme weather accounts for 11% of the loss (Samanta et al., 2021). Events like severe flooding worsen pore water salinity and plant death, while droughts lead to increased evaporation and soil salinity. Both result in lower seedling survival, productivity, and overall mangrove degradation (Ward et al., 2016). Additionally, human impacts contribute to mangrove forest fragmentation leaving the forests less able to act as a reliable storm buffer (Bryan-Brown et al., 2020; Jayanthi et al., 2023; Liang et al., 2023). Martinuzzi et al. (2009) found that mangrove forests near urbanized areas are susceptible to pollution and runoff contamination, and demonstrate a higher probability of being cleared, as flat land is valuable for real estate. Studies show mangrove forests in Puerto Rico have expanded since becoming legally protected in 1972 but restoration is incomplete, as seen below in Figure 6, and mangroves need care to preserve their health *(*Martinuzzi et al. 2009*)*.

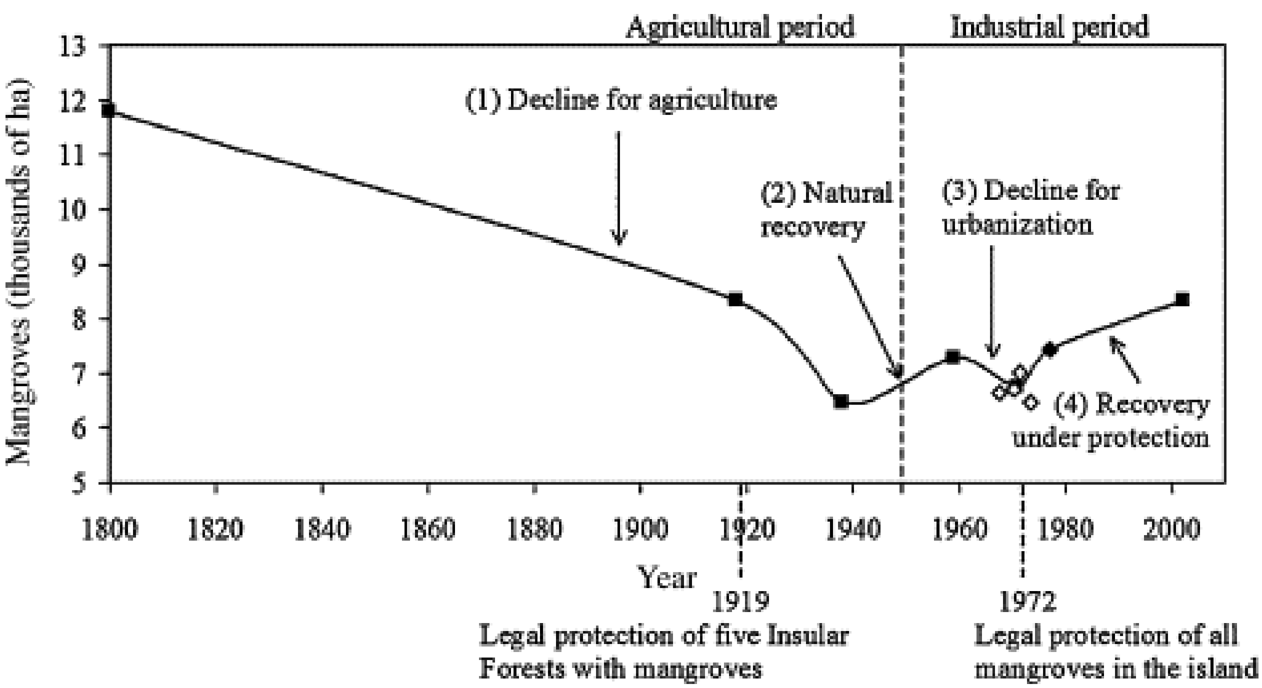

Figure 6: The mangrove population in Puerto Rico
The mangrove population in Puerto Rico has been increasing steadily since 1972, but current levels are significantly lower than they were in 1800 (Martinuzzi et al. 2009).

Because of these vulnerabilities, mangrove forests need to be restored and conserved, which first requires assessment. To assess mangrove risks, previous research has used various data types to analyze different health factors. Studies commonly use Landsat data and satellite images, as well as remote sensing data from Global Mangrove Watch to classify current mangrove forests based on land cover type and detail mangrove extent, net change, and other pertinent information

(Bryan-Brown et al., 2020; Hamza et al., 2022; Jayanthi et al., 2023; Samanta et al., 2021; Soanes et al., 2021). These tools assess many factors to determine the condition of mangrove forests, evaluating data like the color, shape, texture, pattern, and size of the land cover using ArcGIS layers (Jayanthi et al., 2023). Others may include salinization, forest extent, SLR, temperature rise, changes in rainfall, and extreme weather (Bryan-Brown et al., 2020; Samanta et al., 2021).

2.4. Punta Cabullones Natural Protected Area and Verra

Punta Cabullones has over 100 acres of mangroves that sequester carbon and act as an important habitat for wildlife (Para la Naturaleza 2014). This area is managed by PLN, a non-profit organization aiming to protect and restore Puerto Rico's natural environment. Punta Cabullones is especially important to protect because the mangroves act as a buffer zone to the surrounding areas, including the city of Ponce about 5 miles northwest. Punta Cabullones holds several environmental designations: Puerto Rico Priority Conservation, Puerto Rico Critical Wildlife Area, Puerto Rico Waterfowl Focus Area, Coastal Barrier Unit, and Specially Protected Rustic Land. The designations were assigned based on the habitat conservation and buffer zones that mangroves and the surrounding ecosystems provide.

PLN is working with Verra to become certified as a carbon credit provider. Verra is a nonprofit corporation founded for the carbon market's quality assurance and manages the program. The Verified Carbon Standard (VCS) program is the most widely used greenhouse gas credit program globally ("Verified Carbon Standard," n.d.). The program facilitates the financial support of projects working to protect nature and reduce greenhouse gases. As the manager of over 38,000 acres of Natural Protected Areas, PLN is exploring their eligibility to generate carbon credits through the VCS program and are assessing the process and financial implications of selling carbon credits to fund their reforestation efforts.

Methodology

The goal of our project was to evaluate the carbon-sequestering potential of a mangrove reforestation plan at Punta Cabullones and assess the economic benefits of participating in a carbon credit program. To achieve this goal, we accomplished the following three objectives:

1. Investigate best practices to monitor health and carbon sequestering ability of mangrove forests.
2. Determine the requirements to establish and manage a carbon credit certified area.
3. Evaluate carbon credit availability and profitability for the mangrove forest in Punta Cabullones.

In this chapter, we describe our multi-method approach to achieve each objective, as shown in Figure 7. We discuss how our research plan will lead us to develop a process for starting a carbon credit program with Verra using Punta Cabullones as a case study.

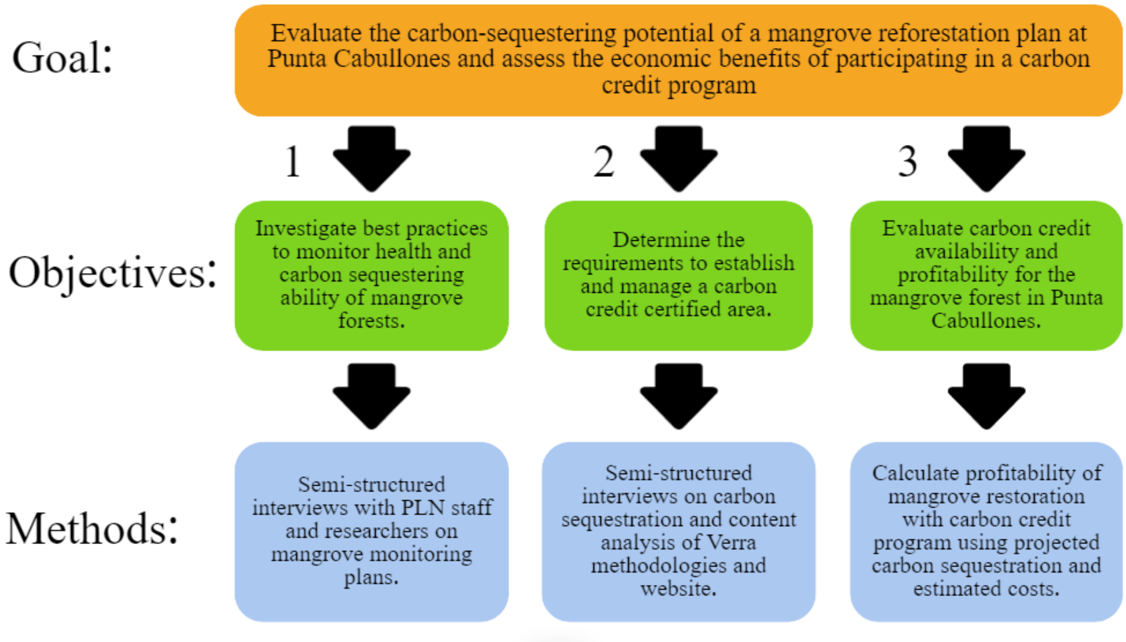

Figure 7: Methodology infographic
This infographic describes the main goal and objectives of the project and the steps the group will take to fulfill them.

3.1. Investigate Best Practices from Local Mangrove Monitoring Plans

The first objective aimed to understand environmental experts' knowledge about mangrove monitoring plans post-reforestation to identify crucial monitoring processes with respect to a carbon crediting program. We conducted eight semi-structured interviews with Dr. Matthew Costa, Dr. Saudamini Das, Dr. Daniel Friess, Dr. Diana Guzmán-Colón, Dr. Ken Krauss, Dr. Christopher Nytch, Juliann Rosado, and Alcides Morales. Refer to Appendix A for these participants' qualifications. Participants included PLN staff members, other environmental group staff or researchers based in Puerto Rico or similar climates who have implemented monitoring plans, and United States Geological Service employees. The team asked our sponsor at PLN, Glorimar Toledo Soto, for suitable Puerto Rican experts to interview and contacted professors cited from research papers used in the background. We scheduled individual, hour-long semi-structured interviews with these participants. Our group asked questions from Appendix B covering mangrove monitoring practices, assessing the indicators of mangrove health, and the use of GIS or other applications to track mangrove progress. We audio recorded and transcribed the interviews, with permission. The team reviewed and annotated the transcripts and used the interview data to outline the most crucial factors to assess the health and monitoring of mangroves.

Additionally, the group visited La Parguera, one of PLN's Natural Protected Areas that has mangrove growth and took the same measurements that volunteers would be taking to measure mangrove health and condition. We planned to take mangrove measurements at Punta Cabullones but were unable to due to weather conditions. However, La Parguera is similar in climate, size, and mangrove coverage to Punta Cabullones, which made it ideal as a substitute. These measured metrics include tree height, diameter of the trunk at breast height (DBH), and quality of the overall tree based on leaf and trunk health. We timed how long it took our group to take these measurements to estimate volunteer measurement time for mangroves in Punta Cabullones. We used a DBH measuring tape, which resembles a regular measuring tape but uses different increments to automatically convert circumference to diameter. We also used a hypsometer which uses a laser to measure height, and a surveying tape measure to create square plots. To determine the quality of the overall tree, we visually inspected the leaves and trunks for discoloration and damage.

3.2. Determine Steps Required to Become Carbon Credit Certified

Our second method determined the process for carbon sequestering programs by interviewing relevant experts in carbon sequestration and carbon credits. Interviewees included relevant professors, PLN staff, and former Verra staff (see Appendix A for more details). We interviewed Dr. Matthew Costa, Amy Schmid, and Juliann Rosado. Interviews used the same format as outlined for the first objective. In these interviews, we inquired about the requirements to certify an area to generate carbon credits, the challenges that commonly arise, as well as how mangroves can be used in carbon sequestration programs, including what data points must be monitored and what tools are ideal for calculating the amount of carbon that can be sequestered from a given sample of mangrove trees. We synthesized the information to inform our other methods, particularly when determining which approach will be most beneficial when completing the carbon sequestration calculations.

In addition to conducting expert interviews, we also informed our carbon sequestration calculations by reviewing Verra's website. Their website is extensive, with five main tabs opening into dozens of sub-tabs that lead to additional reports. Verra includes 40 active methodologies under the Verified Carbon Sequestration (VCS) program, each with its own document of over 100 pages detailing specifications and standards. In addition to VCS, Verra has four other programs on various sustainable eco-social incentives. Their website includes resources for program details, validation and verification, and various other news and events. This information is crucial to perform calculations specific to the Punta Cabullones area. After evaluating the condition of Punta Cabullones, the information provided by Verra determined the VCS methodology fit for the site.

3.3. Estimate Carbon Sequestering Potential in Punta Cabullones

We determined the sequestration rate of implementing the 2021 La Esperanza / Punta Cabullones Reforestation Plan using La Parguera's data. La Parguera, another Natural Protected Area in the south of Puerto Rico, has a similar ecosystem to Punta Cabullones and a known sequestration rate per unit area. We applied the La Parguera sequestration rate as a substitute for the trees being planted through the 2021 Reforestation Plan in Punta Cabullones. By multiplying the sequestration rate per area by the hectares of land being reforested, we found an estimation for the change in sequestration rate of Punta Cabullones.

We determined the profitability of carbon credits to fund mangrove reforestation of Punta Cabullones using estimated costs in the 2021 Reforestation Plan. We compiled data from spreadsheets from the Reforestation Plan as well as the PLN-Site-Based-Project-Feasibility tool, a spreadsheet tool that includes equations and inputs required to calculate the costs, sequestration rate, and profitability of potential carbon crediting projects. Using this data, we calculated the projected cost of implementing a Reforestation Plan in Punta Cabullones. By adjusting for acreage and specifics detailed in the Reforestation Plan, the accuracy of the costs was improved. By using the projected carbon sequestration rate and converting it into carbon credits, as well as the price per carbon credit, we calculated the profitability of the Reforestation Plan.

Results

Our research found that implementing the 2021 La Esperanza / Punta Cabullones Reforestation plan would be beneficial to PLN. It will require some organizational learning and investments, but we determined that it would be profitable and is worth pursuing. We found the Verra methodology VM0033 Tidal Wetlands and Seagrass Restoration to be most relevant to Punta Cabullones for starting a carbon crediting program. The main requirements outlined in Verra's methodology are establishing a baseline, setting up a consistent monitoring schedule, and getting audited. We developed four steps for PLN to follow to comply with Verra's carbon credit guidelines and, in the following section, demonstrate how they would apply to Punta Cabullones. The four steps are shown below:

1. Assess the Benefits of Implementing Carbon Crediting
2. Establish a Project with Verra
3. Evaluate and Adapt Monitoring Standards
4. Conduct Verification for Carbon Credits

4.1. Assess the Benefits of Implementing Carbon Crediting

The first step to implementing a carbon crediting program is assessing the potential benefits. A reforestation or conservation plan must have been designed to evaluate the potential for carbon sequestration. To evaluate the economic benefits, metrics such as sequestration rate, land acreage, and sapling survival rate need to be assessed. These metrics can then be used to outline project-specific costs, such as initial purchasing costs or planting and maintenance person-hour costs. In addition, any project must factor in the costs of establishing a Verra project. These costs can then be combined with the revenue generated from anticipated carbon credits to determine the predicted profits. A description of these calculations can be seen below in Figure 8.

$$Annual\ Profit = Annual\ Gross\ Revenue - \frac{Verra\ Costs}{5\ years} - Annual\ Project\ Costs$$

$$Annual\ Gross\ Revenue = Carbon\ Credits\ per\ Year * Cost\ Per\ Carbon\ Credit$$

$$Annual\ Project\ Costs = \frac{Initial\ Costs}{20\ years} + Annual\ Costs$$

Figure 8: Annual Profit Equations
The image above shows equations used to calculate the annual profit of a Verra Carbon Crediting Project.

By assessing these components, we determined that implementing a carbon crediting program is shown to be feasible for Punta Cabullones. Punta Cabullones has the potential to sequester 990 tonnes of carbon yearly through reforestation. Additionally, PLN is projected to profit an estimated $15,500 annually by participating in the Verra carbon offsetting program.

By implementing the 2021 La Esperanza / Punta Cabullones Reforestation Plan, PLN can double the carbon sequestration rate of Punta Cabullones. Punta Cabullones currently has approximately 100 acres of mangroves, sequestering approximately 1,000 tonnes of carbon annually. According to the 2021 Reforestation Plan, 104.5 acres have been identified for reforestation. With a planting density of about 1,000 trees per acre, roughly 100,000 more mangroves and other trees can be planted. Given a predicted end survival rate between 30% and 60%, an estimated 30,000 to 60,000 trees would survive to maturity, according to Alcides Morales, PLN's Management Coordinator. Adding this many trees, many of which are mangroves, would increase the carbon sequestration rate of Punta Cabullones by an estimated 990 tonnes annually.

Based on the Verra VCS program, if PLN can demonstrate they sequestered an additional 990 tonnes of carbon, they will earn an average annual profit of $15,500, though credits are not distributed yearly. Annual, in this context of profitability, means the aggregated yearly average over the 20 years that the program will run. If they verify the project once every 5 years, they will not earn $15,500 every year but rather $77,500 in the fifth year. PLN has a PLN-Site-Based-Project-Feasibility-Tool spreadsheet that analyzes the carbon sequestration, costs, and profitability of potential VCS projects. The predicted costs, as estimated by the PLN Feasibility Tool, for implementing the 2021 Reforestation Plan as a VCS project will be on average $27,000 annually. These estimated costs come from capital investments of $61,000, covering tasks like planting and marking trees at the start. Annual costs include Verra fees such as project subscription and auditing totaling an average of $10,900, and yearly internal costs, such as weeding and monitoring, totaling an average of $13,000. Although the price of carbon credits fluctuates with the market between about $40 - $80 per carbon credit, using an average price for blue carbon of $45 per credit, according to an anonymous source, PLN will earn an average revenue of $42,500 annually over the 20-year project period. Since many of the costs and carbon credit prices can fluctuate, there is a limit to how accurate these estimations can be.

4.2 Establish a Project with Verra

Before establishing a project, an organization must become accredited with Verra. Once accredited, through our review of the Verra website, there are three main phases to establishing a project with Verra that include: creating the project's description, choosing a methodology in line with the project goals, and validating the project.

After becoming accredited in 2024, PLN will have to create a detailed project description before starting any project. The project description should outline the project's boundary, including geographic perimeter and project goal and processes. A baseline calculation is then created to determine a starting point, defined as the carbon emissions that would be sequestered without adoption of the project. The baseline consists of calculating the change in carbon stock from biomass, soil, and fossil fuel emissions in the area. VCS restoration projects require baseline to be calculated using the latest version of CDM tool AR-Tool02, unless otherwise stated in the project specific methodology.

Selecting the methodology is the second phase of establishing a project with Verra. By choosing a methodology aligned with the project goal and main ecosystem(s), an organization will be able to accurately calculate the sequestration rate and plan for the correct monitoring techniques. PLN has been looking into three different Verra project categories for their Natural Protected Areas. The Afforestation, Reforestation, and Revegetation category will be relevant to many PLN reforestation projects but excludes wetlands and mangroves and will not align with Punta Cabullones. The Reduced Emission for Deforestation and Degradation category that PLN is considering is for sites recently at risk of deforestation. However, Punta Cabullones has been a Natural Protected Area for over a decade, so it is not eligible. Lastly, PLN is looking into Wetland Restoration and Conservation, which aligns best with the mangrove reforestation of Punta Cabullones. Within this category, we identified Verra's VM0033 Tidal Wetlands and Seagrass Restoration as the most relevant methodology for Punta Cabullones. This type of project focuses on creating, restoring, or managing hydrological conditions, sediment supply, salinity characteristics, water quality or native plant communities ("VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v2.1," n.d.).

After detailing the project design and baseline, the project is ready for validation. Validation is the first audit of the project that evaluates project design. The purpose of validation is to assess that the greenhouse gas statement (i.e. the anticipated carbon removal) in the project description follows VCS standards and uses reasonable assumptions and methods. The auditing process is completed by a third party who must follow VCS standards and Verra's validation and verification manual. A site visit by the auditor is required during the validation process, the first verification, any verification with baseline renewal, and any major project deviations to baseline or methodology. The project cannot earn carbon credits on any greenhouse reductions made before validation to ensure the VCS standards.

4.3. Evaluate and Adapt Monitoring Standards

To better understand how PLN may have to improve their monitoring of reforestation efforts, we analyzed PLN's current monitoring practices, reviewed methods for internal monitoring, and compared these with Verra's recommended monitoring standards for VM0033.

Current monitoring at Punta Cabullones is limited due to difficult accessibility and finite resources. PLN manages almost 70 Natural Protected Areas spanning 38,000 acres and must prioritize their reforestation and monitoring efforts. Juliann Rosado, one of the writers of PLN's La Esperanza / Punta Cabullones Reforestation Plan, told us that PLN does not currently conduct any monitoring at Punta Cabullones, mainly due to other Protected Areas currently having higher priority. Monitoring at Punta Cabullones is further made more difficult by the area's muddy terrain and often flooded roads. At other PLN-managed areas, monitoring measures focus on survival due to their institutional goal of retaining at least an 80% survival rate for plantings of all tree species. According to Rosado, mangroves are "very resilient" but if they die, PLN continues replacing them until they adapt to their environment.

Although PLN's experience in monitoring at Punta Cabullones has been limited, they have had success with similar plans in other Natural Protected Areas. Successful mangrove restoration has taken place at Hacienda La Esperanza, a PLN-managed area in the north of Puerto Rico. Alcides Morales, PLN Management Coordinator, oversaw these efforts and described how PLN was able to achieve a 70% survival rate for mangroves through planning and execution. During PLN's Mangleton event in 2021 at Hacienda La Esperanza, volunteers placed a flag when starting to plant seedlings from a bucket, and again at the end. Each bucket had a fixed number of seedlings, and thus PLN noted the approximate location and density of the planted mangroves. After reforestation, Morales and a small group of volunteers monitored the site monthly, focusing more on qualitative data, such as observable predation, approximate mortality rate, or dead and discolored biomass, rather than quantitative, such DBH and canopy height. Six years after planting mangrove seedlings, there were new seeds produced at Hacienda La Esperanza, which is within the normal timeframe for tree maturation. This reforestation effort was successful, in part due to monitoring.

Though we found little documentation of successful mangrove monitoring programs, the few we found used both qualitative and quantitative data to assess their general health. In our interview, Rosado shared that tree measurements and soil samples are key indicators of mangrove health. Tree measurements, specifically those of the root base and DBH, show the growth of a tree over time, the rate of which may change with external conditions. Soil samples can be analyzed for pH and salinity levels, both of which can influence the health of mangroves. Additionally, entire mangrove populations can be assessed using several metrics. According to Dr. Matthew Costa, some of the most critical metrics include stem density, crown height, canopy height, number of plants per unit area, and leaf area index. Taking these measurements when monitoring can help determine if the reforested mangroves are growing normally and are in good health. Leaf area index can be assessed for photosynthetic capacity, which is another indicator of mangrove health, based on the amount of green leaf coverage.

To gather these qualitative and quantitative data, our interviews with PLN employees and other experts pointed us toward monitoring tools and methods that can help ensure the success of a reforestation project. For large reforestation projects, small sections of land are selected as a sample of the property and can be used for both PLN monitoring and Verra monitoring standards. According to Rosado, these "permanent parcels" should represent at least 10% of the total area to provide adequate data. Morales echoed this point, further suggesting that it is also imperative that the permanent parcels represent all the ecosystems found in a given area. For example, if an area has mangroves on the coast, a freshwater stream, and a salt pond, each of those should have a dedicated permanent parcel to avoid skewed data. Establishing these parcels allows monitoring to be conducted consistently and efficiently and can be used to gather the qualitative and quantitative data to assess mangrove health. This technique would be ideal in Punta Cabullones as it has roughly 100 acres of mangroves.

Once permanent parcels have been selected, various tools such as Survey123 or simple flags can be used to collect information about the mangroves' health. Juliann Rosado and Diana Guzman-Colón highlighted the tool Survey123, which allows temporal and spatial data to be collected on mobile devices in the field and integrated with ArcGIS. Guzman-Colón explained that Survey123 is beneficial because it allows users to mark the exact time and coordinates of a data collection point (i.e. a specific mangrove tree), allowing them to return to the exact point in the future and note even minute changes. PLN currently uses Survey123 for some monitoring of planting efforts and Rosado explained that they have templates set up within the app that can convert the data into Excel Spreadsheets where it can be easily incorporated into PLN's database. In contrast to a mobile app, simpler methods can also be used for a less accurate but quicker collection of data, such as the flags used during the Mangleton event at Hacienda La Esperanza. Morales emphasized the importance of using tools that match the capability and experience of the volunteers.

When we visited La Parguera, we discovered that taking mangrove monitoring measurements can be time consuming and weather dependent. We measured the DBH, tree height, and condition of the leaves and trunk for overall tree health using a DBH measuring tape, hypsometer, and visual inspection. It took our group of four students 15 minutes to measure six mangrove trees, considering that we were not familiar with the tools nor were wearing proper outerwear to work in the mudflats. Additionally, it had been raining for multiple days prior, so the mud was very dense and slippery. As such, we reasonably assumed that better trained volunteers, working in pairs or groups of three, would take less time to measure more trees under drier conditions.

The requirements for monitoring under Verra are more rigorous than what PLN may conduct for internal purposes but will increase mangrove reforestation rates and associated carbon credit financial benefits in the long term. The selected methodology, in this case VM0033, specifies all monitoring requirements including what measurements must be taken ("VM0033 Methodology for Tidal Wetland and Seagrass Restoration, v2.1," n.d.). According to Verra, any monitoring plan must include:

- A description of each monitoring task to be undertaken, and the technical requirements therein
- Parameters to be measured
- Data to be collected and data collection techniques
- Frequency of monitoring
- Quality assurance and quality control procedures
- Data archiving procedures
- Roles, responsibilities and capacity of monitoring team and management

Additionally, the frequency of monitoring changes depending on how soon it is after reforestation, as shown in Table 1 below.

Table 1. Timeline of frequency for monitoring post-reforestation under the Verra VM0033 methodology.

Time After Reforestation	Frequency of Monitoring
0 - 3 months	Every 2 weeks
3 - 6 months	Monthly
6 months - 3 years	Every 3 months
3 years - 5 years	Yearly
After 5 years	On an ad hoc basis

4.4 Conduct Verification for Carbon Credits

Once a reforestation project has been validated, it becomes eligible to receive carbon credits after the fifth year of maintenance. A project is awarded carbon credits through a process called verification. The first component of verification is an internal evaluation, in which PLN assesses the amount of carbon that has been sequestered by computing the change in carbon stock. Specifications for how the computations should be carried out are outlined in the selected Verra methodology document. The documentation for VM0033 describes field measurements, literature derived data, and additional considerations that must be accounted for. The field data that needs to be collected is extensive, however not every tree must be measured. This information is then fed into specified equations to calculate the sequestered carbon. After these calculations are completed within PLN, they must be corroborated by a Verra auditor. The auditor conducts both a desk review and a field review to ensure that the calculations were completed accurately. After the verification is approved, PLN will receive carbon credits for the documented change.

Once eligible, a project may select the frequency at which it will be verified. Amy Schmid, a former Verra Employee, now working with Conservation International, recommended that verification take place every five years and no more frequently than once a year. For carbon credits to be issued, significant change must be documented but the auditing process can be expensive due to its thorough nature. Thus, an organization must balance the cost of verification with the gain of carbon credits. The entire verification process must be completed any time PLN wishes to be issued new carbon credits, but carbon credits do not need to be sold all at once. This allows organizations to sell credits with the fluctuation of the market, and to induce revenue as needed without conducting verification again. Figure 9 shows an example timeline for the first few years of a new project.

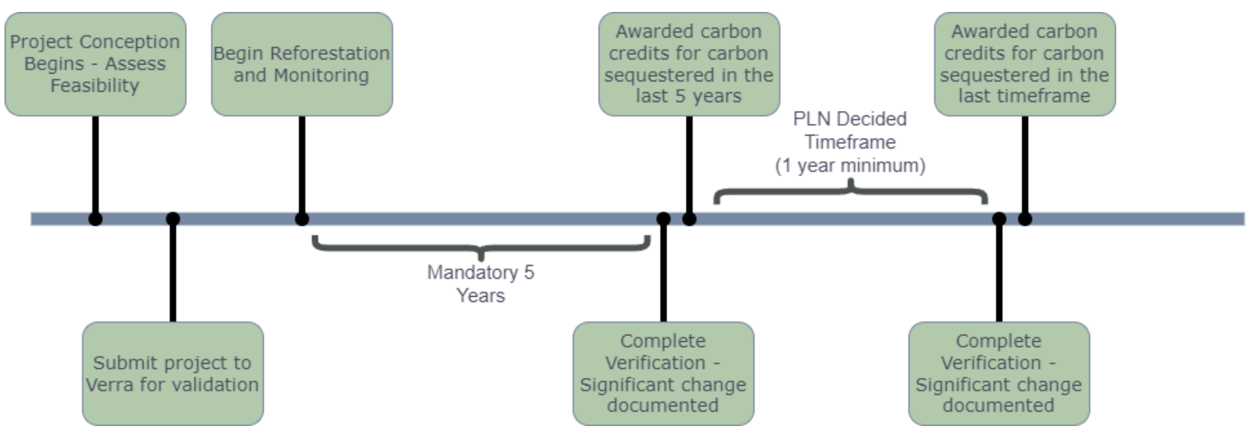

Figure 9: Example timeline for carbon credit project
An example of the timeline for the first 6-10 years of a new carbon credit program. Note that the last timeframe and two steps can be repeated as dictated by PLN so long as the project continues to show significant improvement from the baseline.

Considerations for a Carbon Credit Project

As with any new project, it is important to consider all the factors that may affect the implementation and success of the program. With this feasibility assessment of a carbon credit program in Punta Cabullones, there are many aspects to analyze in terms of the calculations done, Verra's recent controversies, and drawbacks within the carbon credit market.

5.1. Calculations for Sequestration Rate and Predicted Profit

The carbon credit assessment for mangrove restoration in Punta Cabullones involves unpredictable input metrics. Values such as the inflation rate, price of carbon credits, survival rate of trees, and others are difficult to determine with certainty. The predicted profit and sequestration rate for a carbon credits program in Punta Cabullones are likely not the true profit and sequestration rates. Some input metrics, like predicted cost of monitoring and maintenance, are highly variable depending on if PLN uses volunteers or paid employees to implement the carbon crediting program. Calculations get even more unpredictable with volunteers as the price of supervising staff, transportation, and potential stipends would alter the cost, none of which were accounted for in the estimated cost. Additionally, if PLN expands their carbon crediting program to other regions, they will have to redo the calculations for Verra auditing costs in Punta Cabullones. Implementing carbon crediting in multiple separated geographic locations under the same project reduces the auditing cost per hectare. Implementing the project in multiple geographic regions is not accounted for in our profitability calculations since we just focused on Punta Cabullones. Though these calculations are rough estimates, they offer a general assessment to guide PLN's decision to participate in a carbon credit program.

5.2. Logistics of a Verra Program

Due to the complex nature of Verra programs, potential project owners will face many logistical issues when starting their project without the use of external aid. We have seen that Verra has an informative and detailed website, which is important to maintain the high quality and validation of VCS carbon credits. However, it is not very digestible to people who are new to carbon credits and Verra. Through discussions with our sponsor, we have found that PLN has worked with consultants to develop a Verra carbon credit program. Consultants are necessary for organizations like PLN who do not have staff members dedicated full time to developing a program. We had trouble comprehending the steps and procedures of the VCS program until we spoke to someone with years of experience with Verra and VCS projects, which demonstrates the importance of consultants to the program. Dedicated personnel are also necessary to stay up to date with Verra's changing methodologies and standards. There are grace periods for changes in active methodologies, but for new projects, changes can affect plans and cause setbacks.

One important factor to consider when beginning a project with Verra is the organizational size which they are geared toward. Verra is designed to work with larger projects that will earn a substantial quantity of carbon credits, thus justifying the high annual subscription costs. Simply maintaining a Verra project, regardless of size, can cost over $17,500 initially, and $5,000 each year. Even projects that may show high potential for return may not be possible unless they are funded by organizations able to pay the substantial start-up fees. Amy Schmid suggested that projects comprising 1,500 hectares or more are generally more successful, as it can be almost guaranteed that the upfront and maintenance costs will be significantly outweighed by the profits of the issued credits. She added that the cost of carbon credit programs as non-linear relative to size, such that smaller projects cost much more than larger ones on a per-hectare basis. This suggestion raises questions for implementing a carbon crediting program in Puerto Rico. While PLN is one of the largest conservation organizations on the island, many of the areas that it manages have a relatively small acreage. Discussing this point with Schmid, she also informed us that projects do not need to be geographically contiguous. Combining several similar locations and projects into one has the potential to save money, but must be done carefully, as it also has the potential to create an overly complicated project.

In addition to the complex financial aspects, organizations looking to register projects with Verra should also be aware of recent controversy that has sparked around the company. In January 2023, The Guardian, an independent British paper, published an article titled, “Revealed: more than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows.” The article claims that most of the carbon credits bought by companies looking to offset their emissions are “largely worthless and could make global heating worse”. The article, supplemented by independent scientific studies, claimed that Verra overestimated potential deforestation, thus inflating the carbon value of the issued credits. Verra responded to the accusations, arguing that the conducted studies came to incorrect conclusions due to the use of “synthetic controls” which compare a project to a hypothetical scenario in similar environments using set variable factors instead of local factors. There has yet to be a final verdict on the validity of Verra’s issuance of carbon credits. Although these claims are specifically targeted towards Verra’s REDD+ program, which reduces emissions from deforestation and degradation of rainforests and is not applicable to our team’s particular case study, it is important to keep in mind the possible implications of this controversy.

5.3. Carbon Credit Market

The carbon credit market’s variability and the unpredictability of outside factors means that projects contend with a level of uncertainty. Using the Verra methodology, the initial general maintenance and upkeep costs are all upfront since carbon credits can only start being issued after five years. If a disaster occurs, like a devastating hurricane or increased sea level rise, the health of the newly reforested mangroves may be affected, which would decrease the amount of carbon they may be able to sequester. As such, fewer carbon credits would be generated and given a big enough decline, projects may suffer a financial loss. Additionally, the carbon credit market is variable since it is voluntary and the price per carbon credit changes almost daily based on a variety of factors. As Amy Schmid noted, the cost of carbon credits depends on who is buying them and what they are willing to pay for it. Although blue carbon credits generally fetch a better price due to a variety of non-carbon benefits, the cost per credit can differ by almost $40 across various types. Due to this uncertainty with the future health of the reforestation area or cost per carbon credit, there is no guarantee that a project will be successful and carbon credits should be viewed as supplemental income.

Many experts have also noted that there may be aspects of greenwashing within the carbon credit market. The main issues that arise with companies buying carbon credits include double counting credits, using credits in lieu of reducing emissions, and credits not representing actual carbon emissions being removed (Galey, 2022; Raji, 2023; Romm & Schendler, 2023). Double counting credits occurs when both the company trying to offset emissions and the company’s host country count the same carbon credit, falsely improving society’s view of both the company and that country as more sustainable than they are (Raji, 2023). Companies, like Apple, Exxon, Amazon, and Google, will also use carbon credits to claim they, or products they have, are carbon neutral while continuing to emit the same level of carbon dioxide (Galey, 2022; Hyslop, 2022). Some sources also argue that carbon credits do not always represent a tonne of carbon removed from the atmosphere, as discussed above with the Guardian article (Greenfield 2023). The controversy around the carbon credit market remains largely unresolved, in part due to the lack of extensive research and resources on the crediting market.

Since we found few non-Verra resources to explain the logistics of starting a new carbon crediting program, we created introductory material for PLN, as seen in Appendix C. We developed an infographic about the Punta Cabullones case study, emphasizing the potential tonnes of carbon sequestered yearly and the average annual profits. We also developed a fact sheet that introduces the basics of carbon crediting and describes the most relevant methodologies for starting a new project in PLN.

Conclusion

In the next few decades, climate change will affect Puerto Rico drastically, in part due to the increasing carbon dioxide emissions globally. Its effects can be seen through sea level rise, worsening storms, and increasing average temperatures. PLN has been working in Puerto Rico for almost five decades, reforesting the island and conserving the land. Their participation in the carbon credit market stands to offer a new revenue source to support work they are already completing.

Our work found that introducing a carbon sequestration program at Punta Cabullones would be beneficial for PLN to strengthen the environment, sequester carbon, and fund reforestation as well as future projects. We found four main steps to implementing a carbon credit program through Verra, which include: assessing the benefits of implementing carbon crediting, establishing a project with Verra, evaluating and adapting the monitoring standards, and conducting verification for carbon credits. The 2021 La Esperanza / Punta Cabullones Reforestation Plan would also double the carbon sequestration ability of Punta Cabullones from approximately 1,000 tonnes to 2,000 tonnes annually. Through the Verra VCS program, PLN could cover the costs of implementing the reforestation program and additionally make an estimated average annual profit of $15,500 over 20 years, helping to fund other PLN projects. Despite the controversy around carbon crediting, the positive impacts for an environmental organization such as PLN outweigh potential risks. As carbon crediting in Punta Cabullones is shown to be favorable through this study, a further investigation of the benefits of carbon crediting for other reforestation plans is warranted.

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Appendix A: Table of Interviewees

Name	Background	Date Interviewed
Saudamini Das	Indian Economic Services (IES) Professor at Institute of Economic Growth, Delhi, India Primary author: “Mangroves can provide protection against wind damage during storms”	January 18th, 2024
Daniel Friess	Tulane School of Science and Engineering Professor Author: “Framework for facilitating mangrove recovery after hurricanes on Caribbean islands”	January 23rd, 2024
Diana Guzman-Colón	Oak Ridge Institute for Science and Education Fellow United States Department of Agriculture	January 23rd, 2024
Christopher Nytch	Department of Environmental Science Professor - Universidad de Puerto Rico Río Piedras	January 24th, 2024
Juliann Rosado	PLN Reforestation Planning Coordinator	January 31st, 2024
Alcides Morales	PLN Management Coordinator	January 31st, 2024
Ken Krauss	USGS Research Ecologist Primary Author: Framework for facilitating mangrove recovery after hurricanes on Caribbean islands	January 31st, 2024
Matthew Costa	Postdoctoral scholar, Center for Climate Change Impacts and Adaptation at Scripps Institution of Oceanography (SIO) Author: Prioritizing mangrove conservation across Mexico to facilitate 2020 NDC ambition	February 5th, 2024
Ernesto Olivares Gomez	PLN Land Stewardship Manager Former DNER Education Coordinator	February 8th, 2024
Mariana Rivera Figueroa	PLN Southern Region Superintendent	February 8th, 2024
Amy Schmid	Global Blue Carbon Project Lead, Conservation International Former Verra Employee	February 13th, 2024
Anonymous	Former Verra Employee	Undisclosed for privacy purposes

Appendix B: Interview Preamble and Questions

We are a group of students from Worcester Polytechnic Institute in Massachusetts, and we are working with Para La Naturaleza (PLN) to consider the benefits of a carbon sequestration program focusing on mangroves in Punta Cabullones. Currently, we are conducting an interview to better understand your knowledge about mangrove maintenance and monitoring plans in Punta Cabullones and Ponce, as well as carbon sequestration and the carbon crediting process. The interview will take about an hour, at most.

Your participation in this interview is completely voluntary and you may withdraw at any time. We may quote you with your name and identifying information, unless you tell us that you would like to remain anonymous. You will have the chance to review the context in which your quotes appear before report submission. Although our report will be published in our university's library, no names or identifying information will appear in the questionnaires or in any official publications or journals.

If interested, a copy of our results and our audio recording of your interview can be provided through an internet link at the conclusion of the study. Your participation is greatly appreciated.

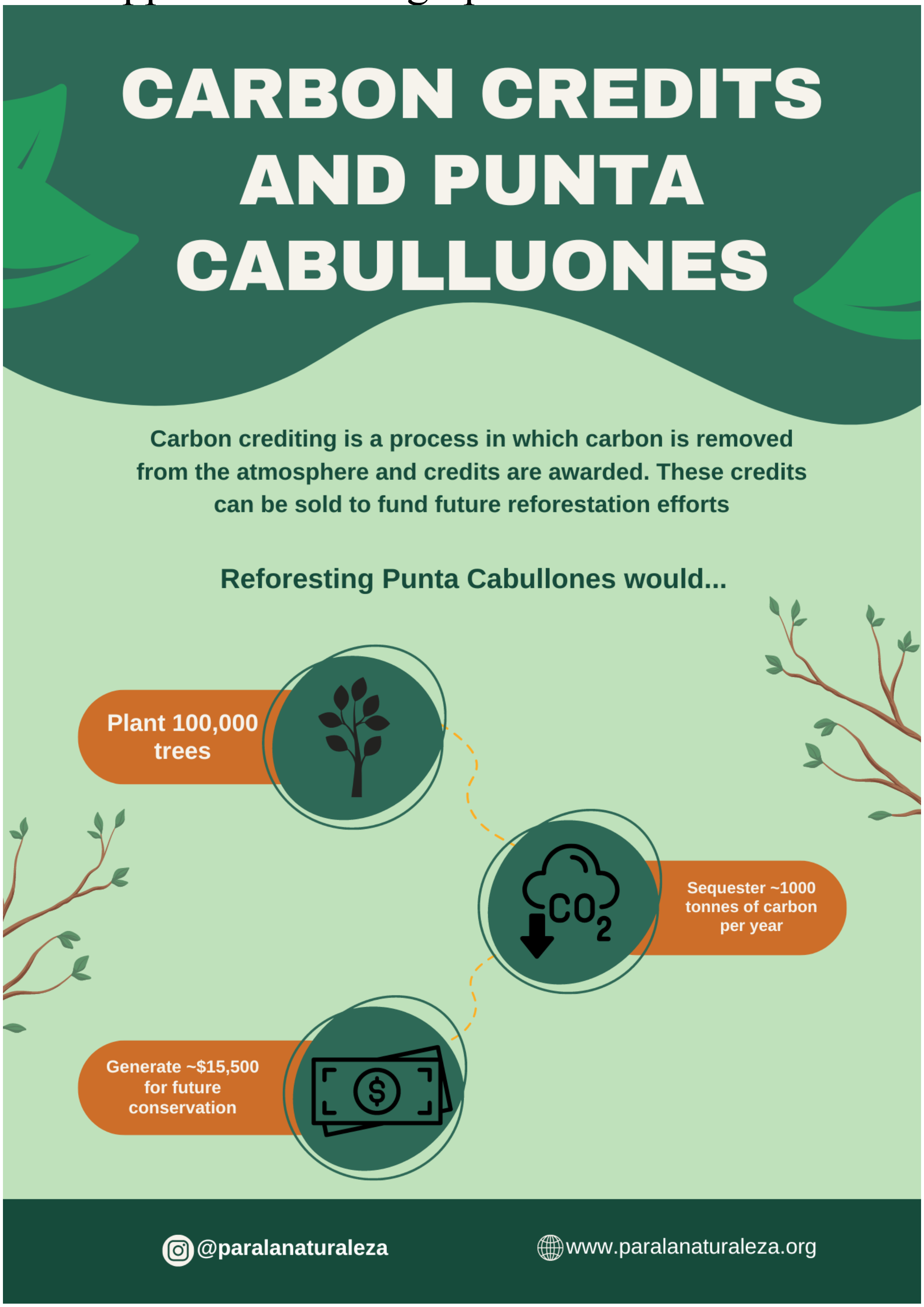
Questions

Specific questions were selected depending on the role of the participant, as shown in Appendix A.

1. With your research on mangrove conservation, we have some questions about maintenance and monitoring.
    a. What was successful about those plans and what did not go well?
    b. What would you improve on for the future?
    c. What resources were most important to your plans?
2. What are some of the best practices of mangrove maintenance you have seen in southern Puerto Rico or similar climates?
3. What are some of the biggest challenges facing mangrove monitoring?
4. Have you ever worked with carbon sequestering? If yes, how was it calculated?
    a. What field data/characteristics need to be collected in order to determine the calculations?
    b. What are some methods you found help you to optimize the collection of these characteristics?
    c. What are some factors you noticed that increase carbon sequestering of mangroves?
5. Have you used GIS in ecosystem modeling and if so, what was your approach? What did you find most helpful from it? Are there any specific strategies or tools you found most beneficial? What were some of the issues that arose when collecting and analyzing GIS data?

6. What would you expect to be the survival rate of mangroves through the mangrove reforestation plan?
7. What is the estimated cost of the reforestation plan?
8. How has the health of mangroves in the area changed since you wrote the mangrove reforestation plan?
9. How successful have past PLN mangrove reforestation plans been?
10. How would you recommend a mangrove monitoring plan be set up for Punta Cabullones?
    a. Are there any tools that you have used in the past (GIS, drones, etc.)
11. How relevant do you think Punta Cabullones would be as a candidate for generating carbon credits?
12. Have you heard of Verra or organizations that work with Verra?
13. Have you heard of any programs on carbon credits in the Caribbean and if so, how successful have they been?
14. Have you done any work in carbon credits?
    a. Have you worked with Verra? Thoughts on their outlined methodologies?
    b. How hard is it to implement an ARR plan?
    c. What is the profitability of an ARR plan (with mangroves)?
15. How familiar are you with the mangrove reforestation plan in Punta Cabullones?
    a. What would you expect to be the survival rate of mangroves through the mangrove reforestation plan?
16. What Verra methodology do you think would be most relevant to the reforestation of Punta Cabullones?
    a. What metrics need to be accounted for to calculate carbon sequestration for that methodology?
    b. Do you have any suggestions for simplifying the process of carbon sequestration calculations?

Appendix C: Infographics and Fact Sheet



Carbon Crediting for NPAs Fact Sheet

What is a carbon credit?

A carbon credit is a permit that allows for the emission of one tonne of carbon dioxide into the atmosphere. Projects that sequester and store carbon or prevent carbon from entering the atmosphere are eligible to earn carbon credits for each tonne they prevent. These credits can then be sold on the open market to other entities.

Who is Verra?

Verra is a nonprofit global organization that sets standards for carbon crediting, verifies carbon crediting projects' emission rates, and issues carbon credits to those projects. One of their biggest and most relevant programs is the Verified Carbon Standard (VCS) which hosts a multitude of methodologies for setting up carbon credit-generating projects.

What are Verra VCS Methodologies?

Verra VCS methodologies are a rigorous set of standards that a project must meet to be eligible for generating carbon credits. These methodologies include requirements, equations to calculate carbon emissions reduced or sequestered, and procedures to follow. Below are a few Verra VCS methodologies that would be most relevant to PLN NPAs.

- VM0007 REDD+ Methodology Framework:
    - Includes reducing deforestation and forest degradation
- VM0032 Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing:
    - Includes reducing carbon emissions from reducing fires, increasing grassland soil sequestrations, and increasing the sustainability of animal grazing
- VM0033 Tidal Wetland and Seagrass Restoration:
    - Includes projects that increase biomass in wetlands through management and restoration efforts
- VM0042 Methodology for Improved Agricultural Land Management:
    - Includes improving practices such as fertilizer application, reduced tillage, water management, and more
- VM0047 Afforestation, Reforestation, and Revegetation:
    - Includes projects that increase woody vegetation and forest density

How to Calculate the Benefits of Implementing a Carbon Crediting Program

Two of the main benefits that can arise out of a carbon crediting program are the reduction in carbon emissions and the profitability of the program. The details for calculating the reduction in carbon emissions can be found in the methodology but the general process is to calculate the baseline carbon emission rates of an area with no intervention and calculate the change in emissions your project would create. To calculate the profitability of a program, subtract the costs from the revenue generated. The revenue can be calculated by taking the number of carbon credits generated, equivalent to the number of tonnes of carbon emissions reduced, and multiplying it by the price per credit on the market. To calculate the costs, sum the Verra program costs, the capital costs, and the annual costs.