Assessing the Need for a Freshwater Ecosystem at the Mrigadayavan Palace Through Soil Conditions

Cha-am, Thailand

Image: Mrigadayavan Palace, Photo by Elizabeth Turnidge

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An Interactive Qualifying Project Report and Interactive Science and Social Project submitted to the Faculty of Worcester Polytechnic Institute and Chulalongkorn University in partial fulfillment of the requirements for the Degree of Bachelor of Science

Sponsored By

The Mrigadayavan Palace Foundation

Submitted By

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Abstract

The Mrigadayavan Palace in Cha-am district, Phetchaburi, Thailand, has faced ecological issues due to seawater intrusion from jetties. Our project goal was to assess the current ecological condition of the palace grounds and communicate the need for a freshwater ecosystem through quantitative evidence on soil and water salinity. We collected supporting evidence through field sampling, archival research, interviews, and observations, determining that the native ecosystem required a low-salinity, sandy environment. To address the saline soil and water, our primary recommendation was regular freshwater recharge to restore the historical salinity of the ecosystem.

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This project would not have been possible without the support of several individuals and organizations from Worcester to Bangkok. We appreciate the time and dedication you gave in helping to produce this report. We would like to thank:

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- **Dr. Anond Snidvongs:** A Mrigadayavan Foundation professor specializing in freshwater/seawater interactions, for providing information on the state of the palace's water systems and how the palace's natural ecosystem has been affected by coastal structures.
- **Dr. Kitichate Sridith:** A Mrigadayavan Foundation professor of botany specializing in sand dune and beach forest ecosystems, for sharing valuable insights on vegetation-related issues and assisting in data collection.
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- **Dr. Sirawat Udomsak:** A professor of geology specializing in sedimentology, field geology, and marine geology at Chulalongkorn University, for providing us with valuable insights into the geological characteristics of Cha-am and its surrounding areas.

Executive Summary

Background

The Mrigadayavan Palace, located in Cha-am district, Phetchaburi, Thailand, was built in 1924 as a seaside residence for His Majesty (HM) King Rama VI. The site of the palace was selected partially due to the abundant underground freshwater resources present in the area. However, following the passing of HM King Rama VI, the palace was abandoned for several decades. As a result, our project sponsor, the Mrigadayavan Palace Foundation, was established in 1992 with the aim of restoring the palace to its original 1924 condition.

Problem

The Mrigadayavan Palace has faced severe ecological challenges due to saltwater intrusion, which contaminates the palace's freshwater resources. This problem, caused by rising sea levels and coastal protection structures (jetties), has disrupted the palace's freshwater ecosystem, compromising native vegetation. The Mrigadayavan Foundation's goal of restoring and maintaining the palace has been made increasingly difficult by the differing interests of other stakeholders in the land, including the Sirindhorn International Environmental Park (SIEP), which requires saltwater to support its mangrove forests. The foundation has a plan to restore freshwater to the grounds but requires the cooperation of other parties. For this reason, our sponsor wants to develop new ways to express its perspective on the need for a freshwater ecosystem.

Goal & Objectives

This project aimed to substantiate the need for a freshwater ecosystem at the Mrigadayavan Palace by examining soil composition, soil and water salinity levels, and vegetation health. By providing empirical data and insights, we sought to support the foundation's restoration initiatives and further its mission of rehabilitating the palace's native environment. In doing so, we sought to answer the question: to what extent can the need for a freshwater ecosystem at the Mrigadayavan Palace be substantiated through the assessment of soil and vegetation conditions?

Our objectives for this project were as follows:

1. Assess the progression of water salinity on the palace grounds.
2. Assess the current ecological conditions of the Mrigadayavan Palace and surrounding areas.
3. Propose research strategies for improving the surface water quality around the Mrigadayavan Palace.

Methodology

To achieve the goal of this project and complete the previously stated objectives, we utilized a multimethod research approach, including archival research, soil testing, data analysis, interviews, and ethnographic observations.

We conducted archival research within the palace archives and through independent investigation to gain an understanding of the historical context of the project and environmental conditions in the area. Additionally, we conducted soil composition and salinity tests to determine the native soil type and the areas most affected by salinity. At each of the soil testing sites, we made observations about vegetation health and the presence of native and invasive species. Finally, we used water salinity data gathered by our sponsor to analyze the impacts of certain events, such as seasonal monsoons, and actions of the foundation, such as the implementation of seawater barriers, on salinity levels. To corroborate this data and capture ecological insights and native species requirements, we interviewed experts at Chulalongkorn University as well as experts working for the Mrigadayavan Foundation.

Key Findings

From the results of our research methods, we developed four main findings:

1. **The native soil indicates the historical presence of a dune ecosystem.**
   Soil composition testing in an unaltered forest area composed mainly of native vegetation showed that the historical soil texture on the grounds was likely sand. This was corroborated by interview results, in which experts described the historical ecosystem as a sand dune environment.

2. **The native local ecosystem requires a low-salinity environment.**
   Through a comparison of the types of vegetation present in soil of varying salinities, we determined that native vegetation was present in higher frequencies in areas where the soil salinity was low. This led to the conclusion that the native ecosystem was less tolerant of saline conditions.

3. **Physical barriers seem to ameliorate salinity issues.**
   In comparing soil and water salinities on either side of the two seawater barriers (the weir and artificial sand dune), we determined that, while the salinity was elevated on both sides of these structures, it was lower on the sides not directly exposed to saltwater influx from the jetties. Additionally, through an analysis of water salinity data over time, we found that after the construction of the artificial sand dune the salinity of the water decreased significantly further during

monsoon season than it had the previous year. This illustrated how the presence of the barriers contributed to declines in salinity but did not entirely resolve salinity issues.

4. **The Mrigadayavan Palace area is in need of freshwater influx.**
   Elevated soil salinity near sources of saline water indicated that saltwater intrusion had begun to affect not only the water on the palace grounds but also the soil. This indicated that a solution had to be implemented to prevent further loss of vegetation on the grounds. Also, through a comparison of the salinities at sites within and outside of these barriers when exposed to monsoon season freshwater influx, we determined that sustained freshwater recharge would be effective at decreasing the salinity within the barriers.

Recommendations

Based on our findings, we developed five recommendations for the Mrigadayavan Foundation. These potential actions were informed by our data-driven findings and expert consultations and aimed to help preserve a vital piece of Thailand's cultural and ecological heritage. The recommendations were as follows:

1. **Artificial freshwater recharge should be implemented to reduce water salinity levels.**
   Our results showed that freshwater recharge would be effective at reducing salinity levels. As such, we recommended implementing a freshwater recharge scheme in alignment with the proposals of a previous study by Kasetsart University.

2. **Zeolite filtering should be explored if freshwater recharge cannot be achieved.**
   In the case that freshwater recharge was ineffective or unattainable, we recommended implementing a small-scale filtration system using zeolite as a filtration medium. This could help to decrease the salinity through inexpensive means.

3. **Trends analyzed in this report should be further explored.**
   As our measurements and analysis were limited by time constraints and challenges in parsing the foundation's data, we recommended analyzing the water salinity data in more depth and over a longer period of time.

4. **The extent of saltwater intrusion should be tested further.**
   Given limitations experienced with time, the depth of soil salinity measurements, and the measurement range of our electrical conductivity meter, we recommended analyzing soil salinity in more locations, with more accurate tools, and further down beneath the soil's surface. Groundwater salinity in the area surrounding the palace and its effect on soil salinity would also be interesting to analyze.

5. **An empirical report on the native ecosystem should be used to support the foundation's goals and coordination among stakeholders.**
   As communicating the need for a freshwater ecosystem to other parties in the area was a primary concern of our sponsor, we recommended developing an empirical report on the needs and characteristics of the native ecosystem. This could include cost analyses and practical solutions that would facilitate compromise between organizations.

Authorship

In the creation of this report, team members took on various roles based on our individual strengths. While all team members were responsible for writing some sections of the report and contributing to the revision of the report in its entirety, the following describes the primary roles that each member typically took on:

Name	**Primary Responsibilities**
Theodore Barnes-Cole	Writing, Report Structuring
Nicolas Graham	Writing, Photography, Compilation of Existing Data, Creation of Salinity Graphs
Chaikit Kittiwatanachod	Writing, Interviewing, Interview Translation
Corinna Petrich	Editing, Formatting, Creation of Maps and Figures, Recording of Field Data
Wannakan Soonthornpornvatee	Writing, Translation of Thai Graphics and Articles, Creation of Maps and Figures
Supanut Sritong-in	Editing, Interviewing, Article and Interview Translation
Chulaphat Staphimolsak	Editing, Interviewing, Translation
Elizabeth Turnidge	Writing, Soil Collection, Soil Testing, Creation of Figures, Photography

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Abbreviation	Meaning
HM	His Majesty
HRH	Her Royal Highness
SIEP	Sirindhorn International Environmental Park
UNDP-BIOFIN	United Nations Development Programme Biodiversity Finance Initiative

Chapter 1. Introduction

The Mrigadayavan Palace, a historically and culturally significant estate in Thailand's Phetchaburi province, currently faces a variety of challenges regarding the ecological condition of the palace grounds. Local vegetation diversity has been substantially impacted by the infiltration of seawater into the palace's fresh groundwater, an inflow brought on by a combination of climate change and local coastal structures. The sponsor of this project, the Mrigadayavan Palace Foundation, aims to restore the palace to its original 1924 condition and is presently engaged in a hard-fought battle to address these saltwater intrusion issues and preserve the freshwater environment. However, this challenge is made increasingly difficult by the differing interests of other stakeholders in the land. For this reason, the foundation wants to develop new ways to express its perspective on the need for a freshwater ecosystem.

The restoration efforts of the foundation thus far have included architectural repair, preservation of the palace grounds, and the restoration of native plant life (Mrigadayavan Palace Foundation, 2017). Previous IQP-ISSP projects have focused on numerous subjects, including water quality, groundwater salinity levels, and restoration of the physical structure of the palace itself (Lockwood et al., 2022; Cohn et al., 2020; Gulezian et al., 2017). However, these reports largely did not address the larger ecosystem being affected by these issues or how to support the foundation in justifying its approach to remedying some of these problems.

In line with this focus, our report sought to compile and visualize data on the condition of the palace grounds to communicate the need for a freshwater ecosystem. Specifically, we aimed to assess the current ecological conditions of the grounds, analyze water and soil salinity measurements to track the progression of salinity, and propose research strategies for improving the surface water quality around the Mrigadayavan Palace.

Recommendations to the foundation were developed through several methods of investigation, namely archival research, semi-structured interviews, ethnographies, and quantitative soil quality testing. These recommendations were outlined in several deliverables, including a detailed report of the findings, the ways that they supported the foundation's goals, and actionable methodology for further research. This enabled us to foster resilience for both the natural and historical aspects of the palace. We hope that in proposing useful preservation and research strategies, we can establish a basis for acceptable compromise and long-term sustainable progress in the Mrigadayavan Palace area.

Chapter 2. Background

The Mrigadayavan Palace Foundation, our sponsor, is focused on addressing saltwater intrusion and the resulting ecosystem changes at the Mrigadayavan Palace in Cha-am, Thailand. In light of this particular goal, the following review aims to academically survey the various issues faced by the foundation, as well as potential recommendations for their resolution. The review also seeks to provide the historical and cultural background necessary to understand the nuances of this particular sustainable development project. The most important concepts identified concerning this goal were the impact of coastal structures on the palace environment, water salinity and its impact on local vegetation through soil conditions, and solutions for supporting freshwater restoration to the ecosystem in alignment with the foundation's mission.

2.1 History and Significance of the Mrigadayavan Palace

The Mrigadayavan Palace, the grounds of which were the subject of our study, was built in 1924 as a seaside residence for His Majesty (HM) King Rama VI, who was in poor health. The king required the palace to be built in a warm coastal climate as a remedy for his rheumatoid arthritis. Cha-am, with its secluded and naturally beautiful beaches, was deemed the perfect location (Mrigadayavan Palace Foundation, 2017; Lakarnchua, 2022).

According to Dr. Kitichate Sridith, the site of the palace was also selected due to the abundant underground freshwater resources present in the area. These reserves were primarily due to the region's coastal dunes, which served as natural reservoirs, allowing rainwater to filter through the sandy soil and restore underground aquifers (Sridith, K., personal communication, February 5, 2025). The dunes' ability to retain freshwater further contributed to Cha-am's suitability as the location for HM King Rama VI's seaside residence, ensuring a reliable and sustainable resource in an otherwise saline coastal environment (Sridith, K., personal communication, February 5, 2025; Gulezian et al., 2017).

With no desire for an expensive and luxurious seaside home, HM King Rama VI drafted simple yet elegant plans and handed them over to Ercole Pietro Manfredi, an Italian architect, to fulfill. The resulting architectural wonder draws on both Thai and Western influences, providing well-ventilated rooms designed to incorporate the calm seaside breeze (Mrigadayavan Palace Foundation, 2017; Lakarnchua, 2022). Figures 1 and 2 show images of the Mrigadayavan Palace in its current condition.

Figure 1

The Mrigadayavan Palace, Cha-am, Thailand.

Note. Photo by Elizabeth Turnidge.

Figure 2

The Mrigadayavan Palace Beachfront.

Note. Photo by Nicolas Graham.

Upon visiting the palace grounds and witnessing their beauty, HM King Rama VI declared that the surrounding area would become an ecological sanctuary encompassing over 3.5 km^2 of land (Mrigadayavan Palace Foundation, 2017). This marked the founding of one of the first zones of conservation in Thailand, indicating that environmental protection and sustainability have long been important aspects of the palace's existence (Yipintsoi, K., personal communication, January 22, 2025). Conservation of the Mrigadayavan Palace and surrounding area is a tradition that serves to honor not only HM King Rama VI and his goals for environmental protection but also the preservation of Thai culture. The king's great adoration for all things culture—particularly literature, theater, and music—was reflected even in his name for the palace. The name Mrigadayavan, derived from that of the Indian deer park where Buddha first began preaching, represents an important aspect in the interconnectedness of Thai religion and culture (Mrigadayavan Palace Foundation, 2017; Gulezian et al., 2017). Despite this enduring commitment to conservation and cultural preservation, the passing of HM King Rama VI caused a challenging evolution in the palace's function and upkeep.

Unfortunately, HM King Rama VI did not live long after the palace was completed and was only able to visit twice, spending a total of five months at his seaside home (Mrigadayavan Palace Foundation, 2017). The palace fell out of use after his passing, driven by diminishing utility, until HM King Bhumibol granted permission for the Naresuan Camp's Air Support Division to use the grounds in 1965. Recognized as a cultural landmark, the Mrigadayavan Palace was registered as a historical heritage site in 1981, leading to several efforts to restore the grounds. Today, the palace is utilized as an educational center and a headquarters for the Border Patrol Police amid continuing restoration efforts (Mrigadayavan Palace Foundation, 2017; Sakunjaroenpornchai & Viryasiri, 2018).

2.2 Sponsor Background

Our sponsor, the Mrigadayavan Palace Foundation, was established in 1992 following the registration of the Mrigadayavan Palace as a historical site. The foundation was established with patronage from Her Royal Highness (HRH) Princess Berjaratana with the aim of restoring the palace to its original 1924 condition (Mrigadayavan Palace Foundation, 2017; Sakunjaroenpornchai & Viryasiri, 2018). According to Director Klaomard Yipintsoi, as cited in an interview with Svasti et al. (2016), HRH Princess Berjaratana had a vision of the palace as a "learning center for the people and a means to express gratitude towards His Majesty King Bhumibol Adulyadej and [her father] King Rama VI." As she was born only shortly before her father passed, the princess saw the restoration of the palace as a way to honor her father's legacy. Through this, she created a place for Thai people to learn about history, culture, and tradition, all things her father cared for deeply (Mrigadayavan Palace Foundation, 2017; Svasti, 2016).

The restoration efforts of the Mrigadayavan Palace Foundation comprise not only architectural repair but also preservation of the palace grounds, including the original flora and fauna present in 1924. Currently, the palace is in the midst of its second large-scale restoration project, addressing issues like coastal erosion, the rehabilitation of vegetation, and the refurbishment of the palace grounds. Previous efforts to address these issues have included the application of vetiver grass to control coastal erosion and the sponsorship of three previous IQP-ISSP projects working towards these restoration goals (Mrigadayavan Palace Foundation, 2017; Lockwood et al., 2022; Cohn et al., 2020; Gulezian et al., 2017). Currently, the foundation's focus has shifted to restoring freshwater to the palace ecosystem in order to rehabilitate the native vegetation (Sridith, K., personal communication, January 22, 2025).

The second mission of the foundation is to serve as an example of sustainable development, promoting education and conservation. The foundation welcomes visitors to the palace, displaying historical exhibits and promoting education through its on-site library and archival records. It exclusively serves the Mrigadayavan Palace and the surrounding community through the many resources and experiences that it offers (Mrigadayavan Palace Foundation, 2017).

2.3 Stakeholders of the Palace Ecosystem

The overarching theme of the preservation efforts around the Mrigadayavan Palace ecosystem has been that of positive intent but haphazard and disjointed execution. Since the declaration of the Haui Sai area as a wildlife sanctuary, several distinct administrative bodies have engaged in stewardship of the area. The Rama VI Military Camp (Border Patrol Police) has the most control in the area, maintaining authority over the other two administrative bodies, the Mrigadayavan Palace Foundation and the Sirindhorn International Environmental Park (SIEP). Notably, a distinct divide exists between the saltwater-based mangrove forest managed by the SIEP and the adjacent freshwater dune ecosystem of the Mrigadayavan Palace (Yipintsoi, K., personal communication, January 22, 2025).

2.3.1 Sirindhorn International Environmental Park

The mangrove forests managed by the SIEP were first planted in 1994 by HRH Princess Maha Chakri Sirindhorn. After discovering salt flats and mud in the local canals, the princess and royal development board came to believe that mangroves historically existed in the area and would flourish in the local conditions (*The Sirindhorn International Environmental Park*, 2022). Mangrove planting and maintenance efforts commenced, notably with the continued addition of mud and, in 2006, the construction of channels within the jetties located on the palace beach to increase saltwater inflow (Gulezian et al., 2017). The park itself was officially established at approximately the same time and has continued to focus on creating mud flats and maintaining the saltwater mangrove forest. This interconnected ecological system, particularly the movement of saltwater resources, has led to differing approaches between the environmental park and the palace foundation as they each work toward their respective ecological objectives (Yipintsoi, K., personal communication, January 22, 2025).

According to Mrigadayavan Palace Foundation Director Kuhn Klaomard Yipintsoi, work is in progress to roll back several substantial alterations to the ecological environment surrounding the palace (personal communication, January 22, 2025). To attempt to restrict the saltwater intrusion onto the grounds, the foundation has constructed two seawater barriers, one on each side of the grounds. Notably, one of the mudflats created by the SIEP to facilitate mangrove growth is in the process of being converted to a more viable "artificial dune." This consists of filling the area with leftover coastal structure debris, mulch, and sand to emulate the native geography (Yipintsoi K., personal communication, January 22, 2025).

2.3.2 Rama VI Military Camp

The Rama VI Military Camp is responsible for overseeing the actions of the other parties present in the area surrounding the Mrigadayavan Palace, including our sponsor and the SIEP. In order to take action in addressing the saltwater intrusion issues on the palace grounds, especially if the foundation wishes to pursue freshwater recharge from the Tah-sa-det reservoir, support must be garnered from this organization (Yipintsoi K., personal communication, January 22, 2025). As they are not obligated to directly interact with the public, limited information was available regarding the goals and influence of the military camp.

2.4 Background of the Mrigadayavan Palace Foundation's Saltwater Intrusion Problems

The Mrigadayavan Palace faces several immediate problems, many of which stem from saline water intrusion into the property. Jetties put in place to prevent coastal erosion have allowed seawater to flow inland, leading to increased salinity in the palace's waterways. Additionally, rising sea levels caused by climate change have further intensified this issue.

2.4.1 Climate Change in Thailand

The ecological impacts of climate change in the Kingdom of Thailand are wide-ranging and have a tendency to worsen many of the issues addressed in this project. Despite being a lesser contributor to climate change, Thailand is likely to be one of the most affected nations. The extensive coastline and tropical climate expose the country to the full extent of various climate change-related disasters. The climate in Thailand is characterized by alternating rainy and dry seasons, meaning that the country is vulnerable to the impacts of both changes in precipitation patterns and drought (de Oliveira-Júnior et al., 2025; Kiguchi et al., 2021; Seeboonruang, 2015; Marks, 2011).

There is a general agreement in the scientific literature that climate change has led to altered weather patterns and changes in the intensity of rainfall in different regions (Kiguchi et al., 2021; Seeboonruang, 2015; Marks, 2011). This includes increases in tropical storms and associated natural disasters (Kiguchi et al., 2021; Marks, 2011). Additionally, global temperature rise has led to a higher probability of drought during the dry season, creating a more dramatic divide between seasonal extremes (Petpongpan et al., 2020; Kiguchi et al., 2021; Marks, 2011). One of the impacts of these changing weather patterns is a decrease in the availability of both surface and groundwater. Drought and fluctuations in locations experiencing intense rainfall lead to declines in water recharge, creating a potential for water shortages (Petpongpan et al., 2020; Seeboonruang, 2015).

A similarly impactful aspect of climate change is rising sea levels. This, in conjunction with the aforementioned increases in extreme weather, leaves coastal communities vulnerable to substantial flooding. These issues cannot be expected to remain static, as flood intensity and frequency are anticipated to increase with time (Marks, 2011; Petpongpan et al., 2020). Climate change-induced sea level rise and coastal flooding have additionally led to saltwater intrusion inland, contaminating water sources and soil. As tides continue to rise, this problem will likely be exacerbated by increases in flooding events (Tarolli et al., 2023; Marks, 2011).

2.4.2 Climatic, Geographic, and Ecological Characteristics of Cha-am

Cha-am, located in a tropical region of Thailand, experiences three main seasons—summer, rainy, and winter—which drive different ecological dynamics. Temperatures range from 19°C to 35°C year-round, and the average annual rainfall is around 1,100 millimeters. Most of this rainfall occurs during the monsoon season from late May to early October, with the heaviest occurring in September and October (*Monthly climate in Cha-am, Phetchaburi, Thailand*, 2024).

Moreover, according to Dr. Sirawat Udomsak, professor of geology and sedimentology at Chulalongkorn University, the ecological effects from seasonal weather patterns differ depending on the season. From October to March, the northeast monsoon drives sand and sediment out into the sea, leading to seasonal erosion. In contrast, the April to September southwest monsoon sees the sediment accumulate back on shore. These processes, combined with the porous nature of sandy soil and rising sea levels, contribute to saltwater intrusion and erosion, which disrupt the coastal ecosystem and threaten biodiversity (Udomsak, S., personal communication, January 24, 2025).

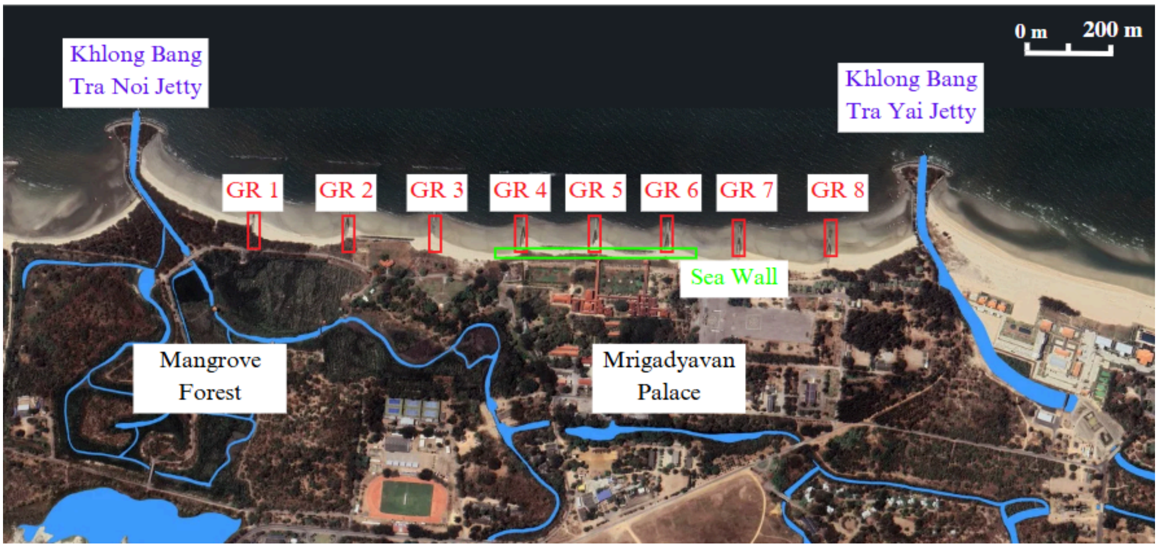
According to Dr. Kitichate Sridith, the Cha-am coastline is composed primarily of sandy soil (personal communication, January 22, 2025). When the palace was first constructed, the surrounding land encompassed a freshwater ecosystem where dunes separated the seawater from the freshwater watershed. A protected area was established surrounding the palace that extended deep inland with the intent of protecting the watershed, in which monsoon season rainfall flows from the mountains and serves to recharge freshwater on the grounds (Sridith, K., personal communication, January 22, 2025). However, reduced rainfall during summer brings about a decline in freshwater levels, leading to increased salinity in estuaries as saltwater intrudes into rivers, similar to the effects observed during flooding. These climatic factors disrupt the ecological balance, particularly affecting plant species that are less tolerant to salinity and highly sensitive to environmental changes critical for their survival. At the Mrigadayavan Palace, water salinity is the main factor influencing the growth, survival, and distribution of vegetation (Sridith, K., personal communication, February 5, 2025; Snidvongs, A., personal communication, February 5, 2025).

2.4.3 The Impacts of Climate Change and Coastal Structures on the Palace Environment

Saltwater intrusion into the Mrigadayavan Palace freshwater waterways has caused a variety of ecological concerns. These issues, initially spurred by climate change, have been exacerbated by the presence of man-made coastal structures such as groynes, seawalls, and, in particular, jetties placed along the palace beach (Mrigadayavan Palace Foundation, 2017). An image of these structures is shown in Figure 3.

Figure 3

Coastal Structures on the Mrigadayavan Palace Beach.



Note. The figure shows a screenshot of the Mrigadayavan Palace beach with the groynes (GR), jetties, seawall, and mangrove forest indicated. Source: Google. [Google Maps Mrigadayavan Palace, Cha-am, Petchaburi, Thailand]. Retrieved February 20, 2024.

In 1997, Tropical Storm Linda removed over 20 meters of coastline near the Mrigadayavan Palace. To address this, the Marine Department implemented a substantial coastal engineering project. The project included two jetties, eight groynes, six submerged offshore breakwaters, a seawall, revetments, and scattered rock formations along a 1.5-kilometer stretch of coastline. These structures have impeded the natural sediment flow from south to north. The result of this is intensified erosion and sediment transport issues downstream of the coastal protection structures (Snidvongs, A., personal communication, February 5, 2025; Sridith, K., personal communication, February 5, 2025). In 2024, a study from the Department of Marine and Coastal Resources found that the groynes disrupted sediment transportation and worsened erosion, even in front of the palace (Patthanamongkol, 2024). As a result, three groynes have been slated to be removed, as shown in Figure 4, to serve as a case study for addressing this issue. In addition to removing the groynes, the stone revetments located between the groynes were dismantled in an attempt to restore the natural beach ecosystem and the coastal sand dune vegetation (Yipintsoi, K., personal communication, January 22, 2025). This is shown in Figure 5.

Figure 4

Coastal Structures on the Mrigadayavan Palace Beach, Indicating Groynes to be Demolished.

Note. The figure shows a screenshot of the Mrigadayavan Palace beach with the groynes (GR), jetties, seawall, and mangrove forest indicated. The rectangle with dashed lines marks three groynes to be demolished. Source: Google. [Google Maps Mrigadayavan Palace, Cha-am, Petchaburi, Thailand]. Retrieved February 20, 2024.

Figure 5

Dismantled Revetment Structure.

Note. Photo by Wannakan Soonthornpornvatee.

Following this, sand fences, shown in Figure 6, were installed along areas where seawater reaches the shore. These fences help to trap sand carried by the tides and reduce the impact of waves near the remaining groynes that have yet to be removed (Patthanamongkol, 2024). The palace has seen improvement of the vegetation as groynes are removed and sand fences implemented, as can be seen in Figure 7.

Figure 6

Sand Fences on the Mrigadayavan Palace Beach.

Note. Photo by Elizabeth Turnidge.

Figure 7

Recovery of the Coastal Ecosystem at the Mrigadayavan Palace.

Note. Photo by Wannakan Soonthornpornvatee

The jetties were first constructed in 2005 to prevent erosion and, shortly after, were opened to bring saltwater inland to support mangroves, which depend on brackish water to survive. Unfortunately, this has had the unintended consequence of allowing saltwater to infiltrate the freshwater sources surrounding the palace (Cohn et al., 2020; Gulezian et al., 2017). This has caused a variety of issues, including reductions in vegetation and a decrease in the amount of available freshwater (Mrigadayavan Palace Foundation, 2017; Cohn et al., 2020). The Mrigadayavan Palace Foundation has been working to remove these structures since 2013 in hope of restoring historical vegetation and refurbishing the palace grounds (Mrigadayavan Palace Foundation, 2017).

2.4.4 The Impacts of Salinity on Vegetation

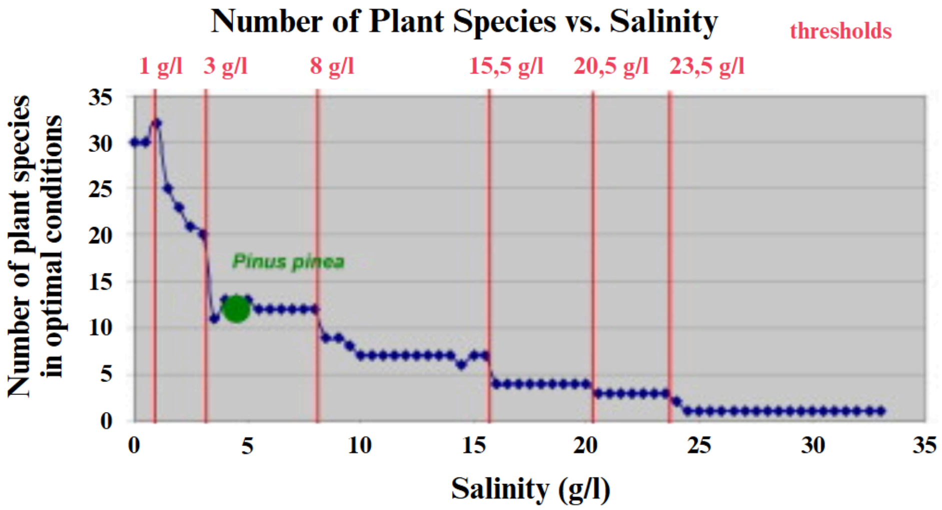
The restoration of the Mrigadayavan Palace grounds necessitates a comprehensive approach to counteracting the effects of saltwater intrusion. Saltwater intrusion occurs when saline water moves from the ocean into a fresh source of groundwater, such as an underground aquifer, or surface water, such as a river or canal. The mechanisms of saltwater intrusion involve many interrelated forces that include sea-level rise, extraction of groundwater, storm surges, and drought conditions. This process significantly alters the chemical composition and properties of the soil and water, which influences plant diversity as a consequence (Michael & The Conversation US, 2023).

A previous IQP-ISSP identified saltwater intrusion as a significant cause of the Mrigadayavan Palace’s inability to grow the desired historical vegetation (Cohn et al., 2020). Elevated salinity levels, driven by climate change and the effects of coastal structures, disrupt local biodiversity and compromise the health of native plant species critical to maintaining the site’s historical authenticity.

It is well-established in the scientific literature that an increase in water salinity results in a decrease in plant life and vegetation diversity (Antonellini & Mollema, 2010; Kaplan & Muñoz-Carpena, 2014; Peters et al., 2020; Ward et al., 2016). Figure 8 shows a graph of the number of species of plants, from a study of vegetation in Italy, that can tolerate different salinity levels. Although these plant species are located in a pine forest in a different climatic zone from Thailand, a similar trend can be seen in vegetation throughout the world (Antonellini & Mollema, 2010).

Figure 8

Number of Plant Species vs. Salinity.



Note. The figure shows the number of plant species, from a study on the effect of salinity on vegetation diversity in Italy, that can tolerate different salinity levels. Source: Antonellini & Mollema (2010).

Saltwater intrusion also changes the composition of entire plant communities. More salt-tolerant species tend to displace the native freshwater species as salinity levels change. As sensitive species are replaced by those better adapted to saline conditions, biodiversity is reduced (Brown et al., 2022).

While water salinity is not the only factor affecting the diversity of plant species in a given location, it is a large determinant of the ability of plant species to survive in that environment (Antonellini & Mollema, 2010; Kaplan & Muñoz-Carpena, 2014). This indicates that addressing the salinity issue at the Mrigadayavan Palace will aid in the foundation's ability to reintroduce and maintain the original plant life present at the time of the palace's construction.

2.4.5 Previous IQP-ISSP Work

Two previous IQP-ISSP teams focused on the saltwater intrusion issues at the Mrigadayavan Palace. In 2017, Gulezian et al. published *Assessing Factors Contributing to Water Scarcity, Impurity, and Coastline Erosion at the Mrigadayavan Palace,* which highlighted water salinity as an increasing concern at Mrigadayavan Palace. This study quantitatively linked elevated water salinity to coastal jetties disrupting natural water flow, unregulated groundwater extraction by local communities, and subsequent freshwater shortage. They also emphasized the need for more frequent and comprehensive monitoring of both water and soil salinity across the Mrigadayavan Palace grounds (Gulezian et al., 2017). Building on this foundation, in 2020, Cohn et al.

published *Assessing the Impact of Human Activity on the Groundwater at the Mrigadayavan Palace in Cha Am, Thailand*. This report focused on practical solutions for mitigating saltwater intrusion, including assessing the effect of modifying or removing existing jetties and exploring desalination techniques to secure freshwater sources (Cohn et al., 2020).

2.5 Addressing Saltwater Intrusion

The jetties on the Mrigadayavan Palace beach have allowed seawater to intrude inland, moving into the freshwater waterways behind the palace. To address this, several methods could be implemented to help mitigate seawater exchange and decrease the salinity of the water.

2.5.1 Utilizing Physical Barriers

Physical barriers can be used to temporarily block water flow, preventing the exchange of seawater between saltwater and freshwater sources. The foundation has implemented this method through the construction of an artificial sand dune, blocking the flow of water in the channel between the northern jetty and the palace's freshwater waterways (Sridith, K., personal communication, February 5, 2025; Yipintsoi K., personal communication, January 22, 2025).

This method has been extensively studied in relation to saline intrusion into groundwater, but few studies exist on its effectiveness in surface water applications. This is likely because entirely blocking the flow in a waterway is often not a viable option. However, in groundwater studies, physical barriers have been shown to be effective in decreasing saltwater intrusion (Li et al., 2018).

In the long term, entirely restricting the flow of water with physical barriers will likely lead the available freshwater resources to become more saline (Onkaew et al., 2007; Snidvongs, A., personal communication, February 5, 2025). The solution to this is the continuous replenishment of freshwater into the water supply.

2.5.2 Freshwater Recharge

Freshwater recharge is also an applicable strategy for addressing saltwater intrusion. Research has shown that replenishing fresh surface water can decrease the extent of saltwater intrusion (Motallebian et al., 2019). At the Mrigadayavan Palace, a report by Kasetsart University examined strategies for mitigating saltwater intrusion through freshwater recharge. In this report, freshwater recharge was shown, in simulations, to prevent saltwater from spreading into the groundwater table, ensuring ecological equilibrium and minimizing detrimental effects on local vegetation and aquatic life (Kasetsart University, 2020).

2.5.3 Zeolite Filtration

In the event that other methods are insufficient at reducing salinity levels, desalination techniques could be used. Depending on the salinity level and budget, several methods are applicable for desalination. Conventional techniques such as reverse osmosis and electrodialysis are effective but prohibitively expensive. However, zeolite filtration could be suitable for this application due to low cost.

Zeolites are natural, hydrated aluminosilicates, and are renowned for their adsorption capabilities, cation exchange properties, and porous structure (Sruthy et al., 2021; Wibowo et al., 2017). Sruthy et al. (2021) demonstrated the effectiveness of natural and thermally activated zeolite filters in reducing salinity levels in water. The researchers used a filter unit composed of non-woven geotextile material filled with zeolite as the primary adsorbent. The system showed significant reductions in electrical conductivity (EC) and total dissolved solids (TDS) (Sruthy et al., 2021).

Implementing zeolite-based filtration systems in the Bang Tra Noi waterways is a practical solution for directly reducing brackish water salinity. The method is cost-effective, as zeolites are relatively inexpensive and widely available (Sruthy et al., 2021; Wibowo et al., 2017). Additionally, unlike some chemical treatments, zeolite filtration does not introduce harmful byproducts into the water or soil. The treated water also maintains a stable pH, ensuring suitability for marine organisms (Wibowo et al., 2017). Filter size can be customized to accommodate varied canal sizes and salinity levels (Sruthy et al., 2021; Wibowo et al., 2017). To implement this filtration system, the materials needed would include natural zeolite (50-300 USD/metric ton or 1.7-10.2 baht/kg), a tank (price varies), sand (easily available), and geotextile fabric (25 baht/m^2) (Sruthy et al., 2021; Williams, 2024; Matiply, 2021).

Chapter 3: Methodology

Based on the information from our literature review, our team identified the most critical issue on the Mrigadayavan Palace grounds as the intrusion of saltwater into freshwater supplies. Through discussion with the foundation, it became clear that the primary value of our project was exploring avenues of research that could be used to support their restoration efforts. However, complications existed in communicating the importance of this native environment to other stakeholders in the area. As such, our focus centered on understanding the context that the palace exists in, analyzing the effects of water salinity on the surrounding soil, and characterizing the native ecosystem. Although quantitative research methods were used, we also incorporated a multi-method qualitative research design to produce more robust and reliable conclusions.

This section outlines methods for evaluating the ecological impacts of saltwater intrusion on the palace ecosystem and exploring research strategies to address the issues faced by the Mrigadayavan Palace Foundation. Archival research, semi-structured interviews, and ethnographies were the three primary qualitative methods utilized in this study. These research methods involved the investigation of archives to provide background on the problem and relevant research on potential solutions, the collection of input from experts, and the gathering of on-the-ground observations to inform on the complexities of solution implementation. This also involved incorporating the needs of the surrounding community and imparting a cultural depth to our research.

Through our various methodologies, we sought to answer the following research question: To what extent can the need for a freshwater ecosystem at the Mrigadayavan Palace be substantiated through the assessment of soil and vegetation conditions? Following this, our goal was to analyze soil conditions at the Mrigadayavan Palace to support the restoration of a freshwater ecosystem.

As smaller steps to accomplishing this overarching goal, the following objectives were developed:

3.1 Assess the Progression of Water Salinity on the Palace Grounds
3.2 Assess the Current Ecological Conditions of the Mrigadayavan Palace and Surrounding Areas
3.3 Propose Research Strategies for Improving the Surface Water Quality Around the Mrigadayavan Palace

3.1 Objective 1: Assess the Progression of Water Salinity on the Palace Grounds

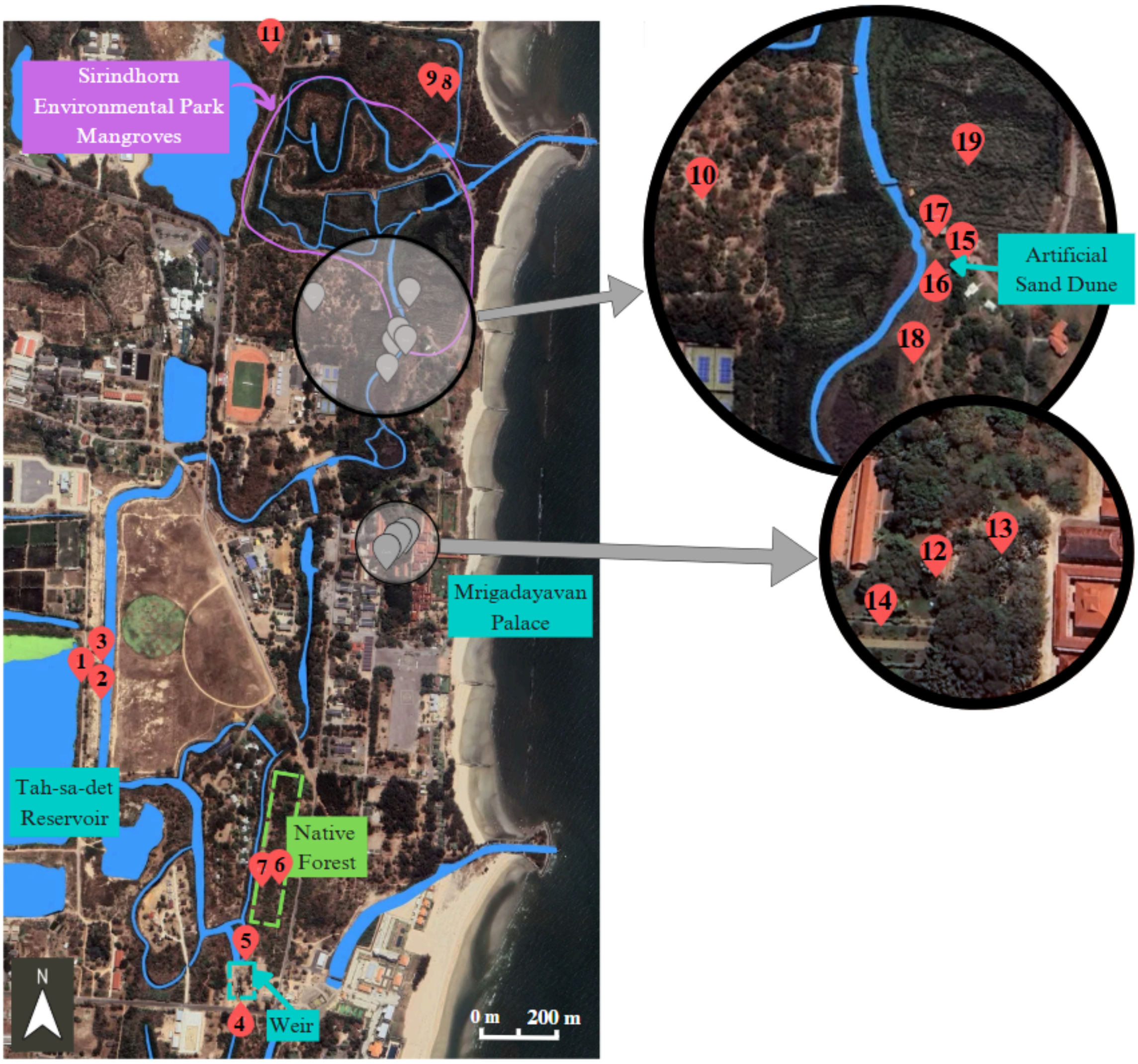
A key aspect of this project was enabling the foundation to communicate the cause-and-effect relationship between their actions to address salinity and the observed salinity levels over time. We analyzed the differences in salinity levels across various time periods and their impacts on the ecosystem, as well as compared the variations in the ecosystem resulting from different salinity conditions. This objective focused on compiling quantitative data, particularly groundwater and soil salinity measurements, into a cohesive report that supported the foundation's goal of demonstrating the necessity of restoring a freshwater ecosystem on the grounds. The research question at the center of this analysis was as follows: How can water and soil salinity metrics be used to prove the need for freshwater influx on the palace grounds?

3.1.1 Soil Salinity Testing

This aspect of the project focused on understanding the environmental condition of the grounds. This was assessed by evaluating and comparing water and soil salinity levels throughout the project site. In the case of water salinity, this data was previously collected by the project sponsor and was provided for our team’s use. Soil salinity measurements were not covered by pre-collected data and were obtained using an electrical conductivity (EC) meter, as shown in Appendix A. We took salinity measurements (measured in μS/cm and converted to dS/m) at various critical locations on and around the palace grounds, including in areas presumed to be predominantly saline or predominantly freshwater environments. These nineteen locations, shown in Figure 9, included the Tah-sa-det freshwater reservoir, the native forest, the base of sugar palms on the palace grounds, and surrounding the artificial sand dune. Using this salinity data, a map of the grounds was overlaid with salinity concentrations. This created an accurate visualization of the spread of salinity in the area, providing a guide for the conditions available for vegetation.

Figure 9

Map of Soil Salinity Sampling Locations.



Note. The figure shows a map of sampling locations for soil salinity, with locations marked in red and numbered.

While providing one piece of the ecological puzzle, this analysis had a limited scope in only considering the salinity of set locations on the grounds. Additionally, the EC meter utilized could measure to a maximum of 4000 µS/cm (4.0 dS/m), correlating with a soil salinity range of slightly saline. However, this salinity is still high enough to impact the health of vegetation (USDA Natural Resources Conservation Service, 2011). Another limitation was that the variable moisture content of the soil in the field could have potentially affected the electrical conductivity measurements. Other important factors in soil and plant health, such as the influence of other contaminants, were not considered in this analysis.

3.1.2 Water Salinity Data Visualization

To provide a useful reference point for saltwater levels throughout the palace, we assembled groundwater salinity data provided to us by the Mrigadayavan Palace Foundation. The foundation has historically collected water salinity data (monthly to weekly, depending on the location) throughout the palace grounds, giving an archive of location-specific measurements. This data was measured in parts per thousand (ppt), and collection locations, shown in Figure 10, focused primarily on key points in the palace waterways. The data was made available by the foundation in Google Sheets documents.

Figure 10

Map of Water Salinity Sampling Locations.

Note. The figure shows a map of the foundation's water salinity sampling locations that were located near our soil sampling sites. Sampling locations not near our soil sampling sites were not considered in our analysis.

Taking the data provided by the foundation, we created graphs in Google Sheets of the water salinity at each location across a period of around two years, from October 2023 through January 2025. In these graphs, we included shaded regions for monsoon seasons to depict how freshwater influx affected the salinity of different locations surrounding the palace grounds.

In the extensive spreadsheet provided by our sponsor, the data was presented in Thai, much of the information was not applicable to our project scope, and some gaps existed in collection periods. This led to some difficulties with data translation, cleaning, and visualization.

3.2 Objective 2: Assess the Current Ecological Conditions of the Mrigadayavan Palace and Surrounding Areas

To evaluate the current conditions of the Mrigadayavan Palace and its surrounding areas, our team employed both a qualitative and quantitative approach, focusing on ecological health indicators and gathering ethnographic information. These metrics were essential for answering the question of how environmental and cultural factors influenced the site of the Mrigadayavan Palace.

3.2.1 Ecological Health Assessment

This method prioritized assessing the impacts of soil and water salinity on the Mrigadayavan Palace grounds and vegetation. This centered around accompanying salinity data with observations focused on how salinity impacted vegetation health. Each sample site (as seen in Figure 10) was evaluated based on factors such as the presence of key native and invasive species, estimations of the overall vegetation cover, and the physical appearance of plants in the area. Additionally, to provide a clearer understanding of the impact of seawater intrusion and environmental changes, we compared these conditions on palace grounds with the site of the SIEP, identifying key differences in ecological health and landscape characteristics. To simplify this process, visual surveys were used to observe species composition, distribution, and density. On the palace grounds, this consisted of working with Dr. Kitichate Sridith, the foundation's resident botanist, to compare the vegetation at each sample site and identify which species of plants were native or alien. We documented our findings through notes and photographs during our visits.

Our data analysis for this method primarily involved mapping out the areas with the highest occurrences of native and invasive plants and comparing these findings with the soil salinity measurements in these same locations. The physical appearance of plants at these sites was also evaluated to determine if a correlation existed between elevated salinity and the declining health of vegetation. Through evaluating the ecological health of the palace grounds in comparison to SIEP, we expected to gain an understanding of how water and soil salinity affected the composition of species in the area.

While providing useful specific data, this work was constrained by our capacity as a team to analyze and assemble information. Large-scale analysis of this type is best implemented by a larger team with more significant resources and greater expertise. Additionally, vegetation health was evaluated solely based on physical appearance rather than other biological or chemical health indicators.

3.2.2 Evaluating the Historical Ecosystem through Soil Composition

The Mrigadayavan Foundation made the claim that the historical ecosystem of the palace grounds was dominated by sand dunes, freshwater, and sandy soil. To evaluate the validity of this claim, thus confirming the need to revert the palace grounds back to a freshwater ecosystem, we performed multiple tests of soil composition at various locations on the palace grounds and in surrounding areas. These locations correlated with many of the ones tested for soil salinity and are shown in Figure 11. At each location, we collected approximately 200 cm^3 of soil from around five centimeters below the surface.

Figure 11

Map of Soil Composition Sampling Locations.

Note. The figure shows a map of sampling locations for soil composition. For simplicity, as the sites overlap with those measured for soil salinity, the site numbers remain unchanged. For example, site 3 is not shown in this map because this location was tested for soil salinity but not composition.

The first soil composition test, the ribbon test, involved physically feeling the textural characteristics of the soil. We accomplished this by taking a small handful of soil, moistening it, and then kneading it until the soil became a more uniform texture. During this process, we observed whether the soil felt gritty, smooth, or neither. Then, we formed the soil into a ball and pressed it into a ribbon until it broke. We measured the length of the ribbon, with a longer ribbon indicating that the soil contained a greater amount of clay (Ritchey et al., 2015).

The second soil composition test involved exploiting the differential settling velocities of sand, silt, and clay. We filled mason jars approximately ⅓ of the way with soil and ⅔ with water before sealing the jars, shaking them up to create a uniform mixture, and allowing the soil to settle undisturbed. We then measured the depth of the soil settled at the bottom of the jars after one minute, two hours, and 48 hours, which indicated the amount of sand, silt, and clay, respectively, that was present in each sample. Jeffers (2023) effectively describes this methodology in more depth. The results of this soil composition test for each location were then compared to the first to ensure the accuracy of the results.

3.2.3 Ethnographic Evaluation

An important component of our research was understanding and communicating not only the physical but also the sociological environment that the palace exists in. This work primarily revolved around understanding the cultural significance of the palace and the actual usage of the palace and grounds. We observed physical locations throughout the palace grounds, including gardens, perimeters of the property, and common spaces. Much of the time spent interviewing various individuals at the palace was in the staff common eating area, while our time spent conducting fieldwork ranged throughout the property. We also were able to tour the palace itself, making observations as we worked and experiencing the respect with which the staff treated it.

The primary focus of this ethnography was understanding how people from various contexts interacted with each other and the palace. This allowed us to establish a more complete view of the condition of the palace and the role it occupied in the community. Our observations were limited to the palace grounds, meaning broader cultural factors or external influences may not have been completely represented. Additionally, the findings reflect the research team’s perspective, which could have introduced subjective bias and may not represent the experiences of local communities not directly involved with the palace.

3.3 Objective 3: Propose Research Strategies for Improving the Surface Water Quality Around the Mrigadayavan Palace

The Mrigadayavan Palace Foundation wishes to restore freshwater to the palace ecosystem, counteracting the effects of jetty construction. The foundation has contended that decreasing the salinity of the water on the grounds is essential to restoring historical vegetation. To investigate the validity of this claim, determine the ability of the palace ecosystem in its current state to sustain freshwater, and recommend research strategies for assessing the native ecosystem, we conducted interviews with the various experts. The research question addressed by this objective was: How can the foundation both begin to approach freshwater recharge and build upon our research to support continued restoration efforts?

3.3.1 Interviews with Non-Foundation Experts in the Field

To obtain an outside perspective from knowledgeable individuals on the problems faced by the Mrigadayavan Palace Foundation, we interviewed several experts in related fields. Dr. Sirawat Udomsak, a geologist from Chulalongkorn University specializing in sedimentology, field geology, and marine geology, provided insights into the geological processes influencing seawater intrusion and its impact on coastal environments. Additionally, Dr. Chanita Paliyavuth, a botanist with expertise in wetland ecology and plant ecophysiology, contributed valuable knowledge on how changing water salinity affects plant communities and the overall ecosystem resilience of the palace grounds. Both of their insights were particularly valuable in understanding how the current ecosystem has shifted from its original state and what the native ecosystem of the area was supposed to look like before these environmental changes occurred.

To further explore these insights, we conducted semi-structured interviews with both experts, recording the discussions with their permission using voice memos. The majority of the interviews were held in Thai and later translated into English. A complete list of interview questions, available in both languages, is provided in Appendix B. Some examples included:

1. How can ecosystems as a whole be impacted by increases in water salinity?
2. What, in your opinion, should the Foundation do to address its issues with regards to water salinity?

We used the script located in Appendix D to obtain informed verbal consent, ensuring that our interviewees were participating willingly and with the best possible knowledge of the potential risks involved. We further obtained verbal consent to use any identifying information about our interviewees, with the understanding that this was entirely voluntary, and every participant was entitled to their anonymity.

One limitation of this method was the potential for translation inaccuracies, which could have led to slight misinterpretations of the original responses. Additionally, conducting interviews in Thai may have influenced how participants expressed their thoughts compared to if they were conducted in English, due to linguistic and cultural context differences.

3.3.2 Interviews with Mrigadayavan Foundation Experts

In order to achieve an in-depth understanding of the historical and current issues present at the palace, we interviewed two key experts who work closely with the Mrigadayavan Palace Foundation. The first, Dr. Anond Snidvongs, had a background in geoinformatics and has worked extensively in freshwater/seawater interactions. He provided a comprehensive discussion about the history of the coastal protection structures, the various associated seawater intrusion issues, and the steps the foundation has taken toward dealing with these issues. Interview questions focused on specific seawater intrusion issues around the waterways and the palace, including the problem of ecosystem effects from the surrounding area. We also interviewed Dr. Kitichate Sridith, a renowned botanist who has worked with the foundation for many years. This interview primarily centered around understanding the native sand dune ecosystem, its characteristics, benefits, and the challenges that it has faced over time.

These interviews were conducted primarily in English and were also recorded with the permission of the interviewee. We followed the same ethics procedures described in the previous section. A complete list of interview questions, available in both Thai and English, is provided in Appendix C. Some examples included:

1. How would you describe the native ecosystem at the Mrigadayavan Palace prior to human intervention?
2. How has the water salinity changed in recent years?

3.3.3 Formulate Research Strategies for Improving Surface Water Quality

Fundamentally, this project was intended to act as a useful starting point in developing research methodologies for the Mrigadayavan Palace Foundation. The two significant strategies we explored were as follows: comparing soil to water salinity and analyzing native ecosystem characteristics. These both fundamentally focused on demonstrating how our methodologies provided value and could be expanded upon in the future by the foundation.

Finding a correlation between soil and water salinity allowed us to observe and understand the extent of saline intrusion on the palace grounds. However, the comparison was limited to the current period, as historical soil salinity data was unavailable for long-term analysis. In comparing these two metrics, we used the foundation's most recent water salinity measurements and our own soil salinity tests. Both measurements were ranked on a scale of non-saline to highly saline, as the two quantitative values could not be directly equated. The soil salinity values were compared to the classes adapted from the NRCS Soil Survey Handbook (USDA Natural Resources Conservation Service, 2011). The water salinity values were compared to the water salinity status chart in

Measuring Salinity of Water (2016). This allowed us to make observations about how water salinity influenced local soil conditions.

Additionally, water salinity was analyzed over time and matched to physical occurrences. Two significant events were evaluated in conjunction with water salinity: the yearly monsoon season (as it represented a massive influx of freshwater) and the installation of the foundation’s artificial sand dune in mid 2024 (as it was presumed to prevent the flow of saltwater from the northern jetty).

Analyzing the local ecosystem also involved the combination of several methods of data collection. Soil sampling and salinity measurements were used to characterize local conditions throughout the area and focused on accurately describing the ideal conditions for the native ecosystem. These were used in conjunction with observations of native and alien vegetation in corresponding areas, enabling us to describe the impact of the change in soil conditions.

These combined analyses allowed us to evaluate the effectiveness of various potential solutions in ameliorating salinity issues, most notably the freshwater recharge described in the report from Kasetsart University (Kasetsart University, 2020). We also used this analysis to demonstrate the value of creating an empirical assessment of the palace’s native environment to prove the needs of the native ecosystem more conclusively.

Chapter 4: Findings

This chapter outlines our findings resulting from the compilation of data collected through our various research methods. In seeking to substantiate the need for a freshwater ecosystem at the Mrigadayavan Palace through the assessment of soil and vegetation conditions, our team came to several conclusions. Through an assessment of the current ecological conditions of the palace grounds, we found that the native freshwater ecosystem, a sandy forest habitat, had been damaged by the influx of saltwater from jetties intended to support the nearby cultivated mangrove forests. In modeling water salinity progression, we determined that although several barriers had been installed near both jetties to prevent the influx of saltwater, these served only to reduce saltwater intrusion rather than resolving the issue in its entirety. Finally, in seeking to propose research strategies for improving the palace's surface water quality, we found that to adequately support its native ecosystem, the Mrigadayavan Palace Foundation would need to implement a constant recharge of freshwater resources.

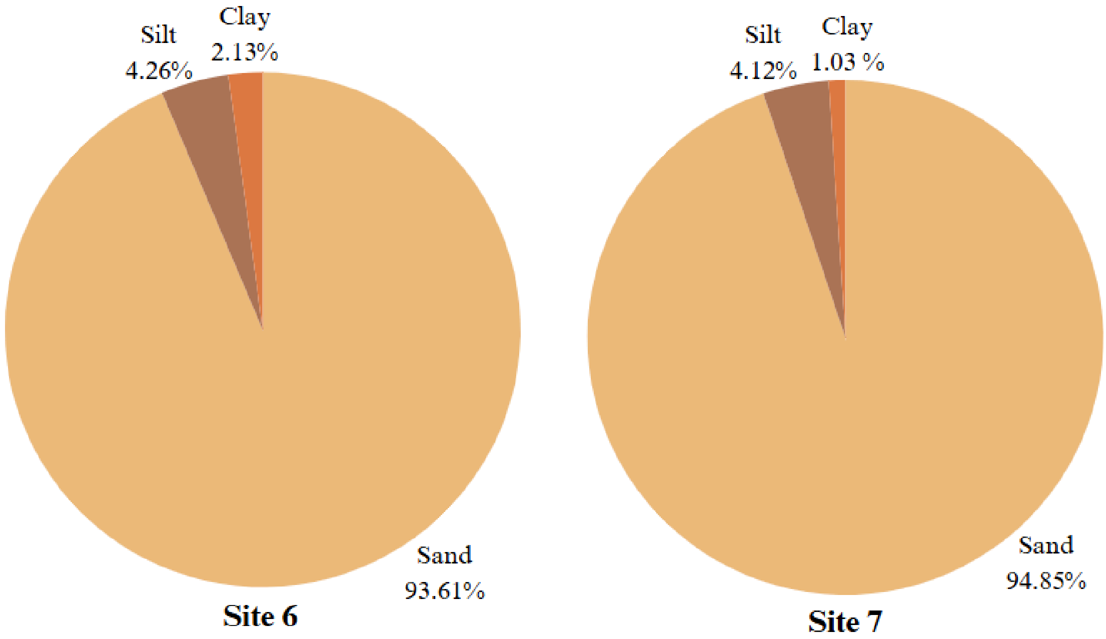
4.1 Finding 1: The Native Soil Indicates the Historical Presence of a Dune Ecosystem

Through interviews with experts from both the Mrigadayavan Palace Foundation and Chulalongkorn University and our own soil testing, we determined that the native ecosystem of the palace was likely a dune-based beach forest. Dr. Chanita Paliyavuth and Dr. Kitichate Sridith both mentioned that the historical ecosystem was once composed mostly of sand dunes intermingled with sparse but flourishing native vegetation. They claimed, however, that developments in land utilization, like urbanization and the cultivation of mangroves, significantly altered the ecological landscape. As a result, sandy soil in a historically unaltered area of the grounds would be an essential indicator of a coastal dune ecosystem (Paliyavuth, C., personal communication, January 24, 2025; Sridith, K., personal communication, February 5, 2025).

To validate these claims and begin characterizing the ecosystem historically present at the Mrigadayavan Palace, we assessed the soil characteristics in the surrounding area. Based on the results of the ribbon test for soil composition in the native beach forest (sites 6 & 7), we determined that the historical soil texture was likely sand. The differential settling velocity test, shown in Appendix E, confirmed these results, indicating that the primary constituent in the soil in this location was sand. The percentage breakdown of the soil composition from these two sites is shown in Figure 12.

Figure 12

Soil Composition Breakdown Sample Sites 6 & 7 in the Native Forest.



Note. The figure shows the results of soil composition gathered through the differential settling method for sites 6 and 7.

This finding was additionally corroborated by the sandy texture of other soil samples taken around the palace. Table 1 shows the soil composition results for each of the sample sites (as depicted in Figure 11), indicating that in most sample locations the primary component of the soil was sand. While some of the results of the ribbon test did not match the results of the differential settling test for a given site, this was unsurprising, as the ribbon test was more dependent on the subjective observations of an individual. As such, when the two test results differed, the differential settling results were taken to be a more reliable indicator of the actual soil composition.

Table 1

Soil Composition Results for Each of the Sample Sites.

Site #	Ribbon Test Texture	% Sand	% Silt	% Clay	Differential Settling Texture
1	Loamy Sand	86.2	10.3	3.4	Sand/Loamy Sand
2	Loamy Sand	84.6	15.4	0	Loamy Sand
4	Clay	20.0	0	80.0	Clay

5	Silty Clay	0	0	100	Clay
8	Sand	100	0	0	Sand
11	Clay Beneath Sand	72.0	24.0	4.0	Sandy Loam
12	Loam	83.8	16.2	0	Loamy Sand
14	Loamy Sand	65.0	0	35.0	Sandy Clay Loam
18	Loamy Sand	56.3	40.6	3.1	Sandy Loam
19	Clay	0	0	100	Clay

Note. The table shows the soil composition results for each of the sample sites located on the palace grounds and in the area surrounding the palace. Sites 3, 6, 7, 9, 10, 13, 15, 16, and 17 are not shown because these sites were tested only for soil salinity, not composition. Some composition percentage rows do not add to 100%. This is due to rounding.

The most notable outlier obtained was site 14, where sandy clay loam was found to be present on the palace grounds. This could be explained by the fact that this sample site was located in a garden, meaning that the soil composition could have been altered from the presumed original sandy state. Sites 4, 5, and 19 were found to be composed of clay; however, these sites were located near the weir and in SIEP, both areas where outside soil was brought in to build up the banks of the channel or cultivate mangroves, respectively. Finally, sandy clay was found at site 15 on the artificial sand dune, another location where the soil was obtained from a secondary location.

While the corroboration of interview results and multiple tests of soil composition suggested that the area was initially a dune ecosystem prior to human intervention, a larger sample size for soil composition measurements could provide more compelling evidence to support this conclusion. This larger sample size could include more samples in the SIEP, in other native forest areas, and in more locations around the palace grounds.

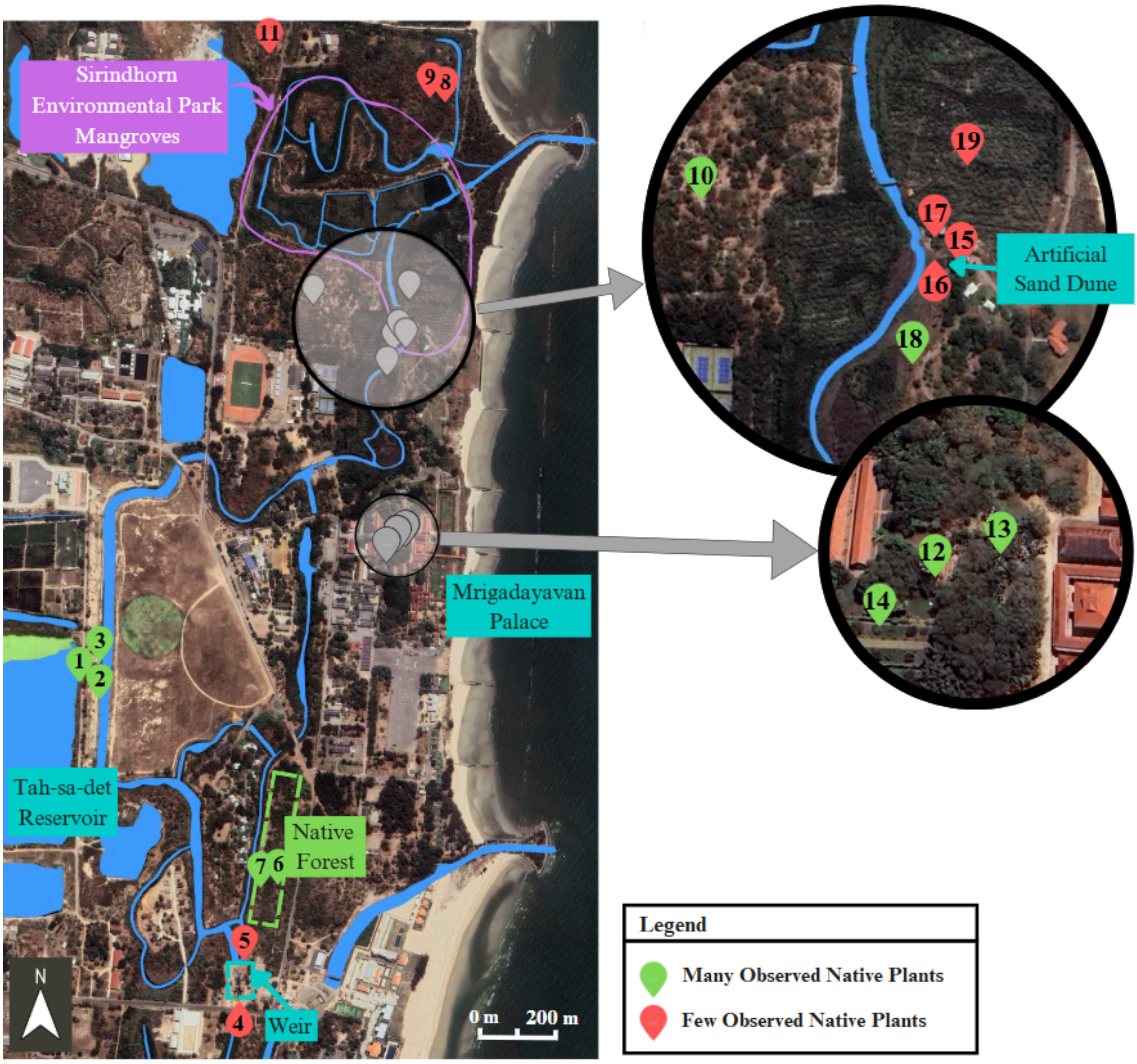
4.2 Finding 2: The Native Local Ecosystem Requires a Low-Salinity Environment

A key aspect of our research was not only understanding the current conditions of the palace ecosystem but also identifying optimal conditions for the regrowth of native vegetation. We observed the growth of both native and non-native species, compared the soil salinities in the areas with high and low occurrences of native plants, and, through this, determined that the native local ecosystem required a low-salinity environment.

Figure 13 shows the locations, around our soil sampling sites, where high and low occurrences of native vegetation were observed.

Figure 13

Map of Native Plant Species Occurrence at the Soil Sampling Locations.

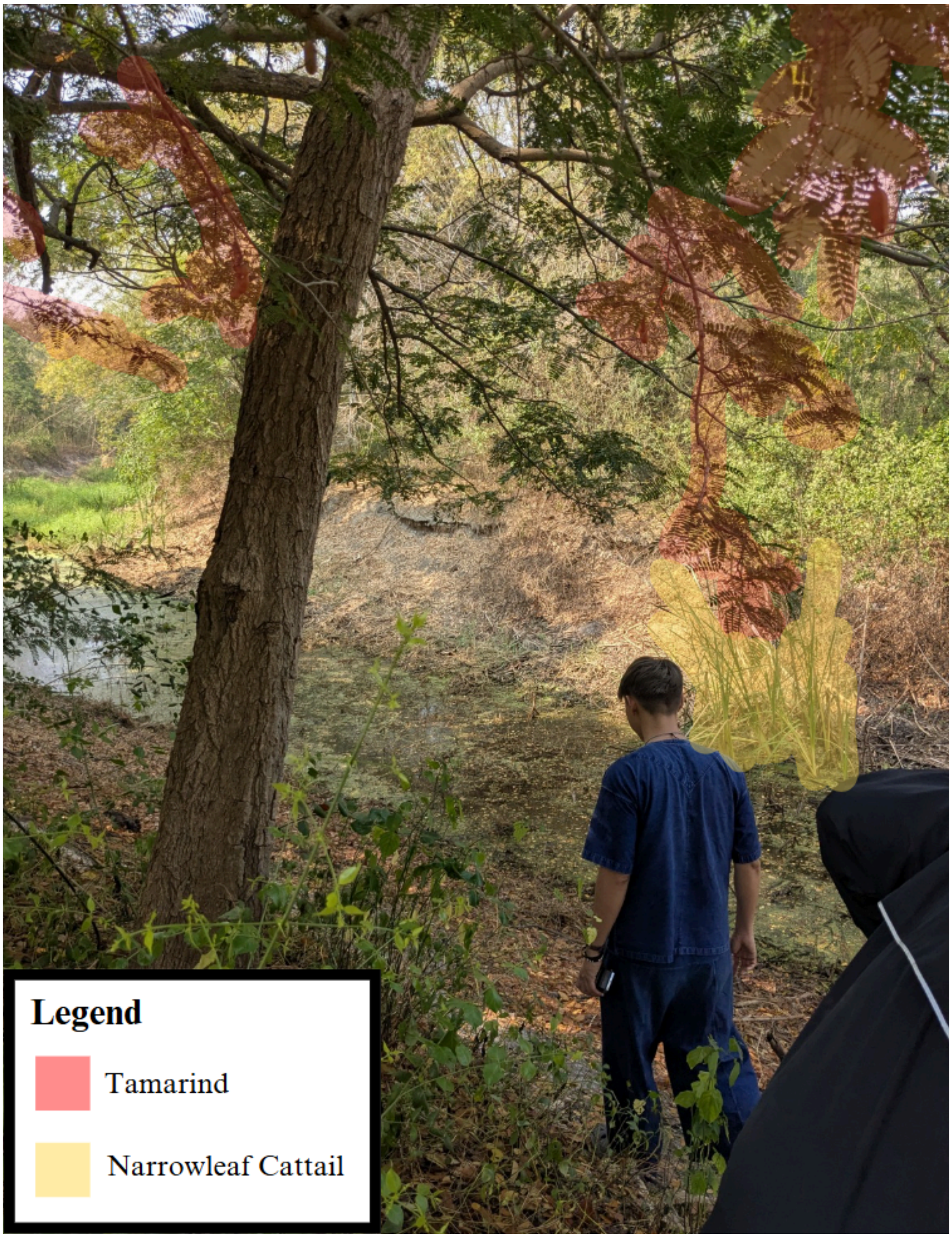


Note. The figure shows a map of soil sampling locations categorized by the presence of native plant species. Green markers represent locations in which many native plant species were observed, while red markers indicate locations where there were few observed native species.

Around the Mrigadayavan Palace grounds, we observed an increase in native species in locations where the soil was less saline. Invasive species were observed at most of the sites we visited, but the relative frequency of invasive species was higher at saline sites. For example, Figure 14 shows soil sampling site 11, which contained several invasive species of plants, including tamarind and narrowleaf cattail. These species were identified based on the invasive species chart shown in Figure 15, which was provided by the Mrigadayavan Palace Foundation. The soil salinity measured in this location had an average value of 2.41 dS/m. For comparison, in the native forest, an area with a high occurrence of native vegetation around sites 6 and 7, the measured salinity had an average value of 0.004 dS/m.

Figure 14

Invasive Species of Vegetation at Site 11.



Note. The figure shows several invasive species present at soil sampling site 11. These invasive species include tamarind (marked in red) and the narrowleaf cattail (marked in yellow). Photo by Elizabeth Turnidge.

Figure 15

Invasive Species Identification Key Translated into English.

Note. The figure shows a key for identifying invasive species in the Mrigadayavan Palace area. This key was provided by the Mrigadayavan Palace Foundation and translated by Wannakan Soonthornpornvatee.

One of the most important native species we observed was the sugar palm. Sugar palms are freshwater trees that are very sensitive to saline conditions, meaning they require freshwater to survive (Sridith, K., personal communication, February 5, 2025). The soil salinity around the base of the sugar palms was very low, with the highest recorded measurement being 0.073 dS/m. Therefore, we concluded that native vegetation was less tolerant of saline conditions.

Contrary to the relative occurrences of other invasive species, we observed a large number of invasive cacti all around the palace grounds, especially in native forest areas. This could be explained by the fact that both cacti and the native vegetation thrive in dry, sandy environments.

4.3 Finding 3: Physical Barriers Seem to Ameliorate Salinity Issues

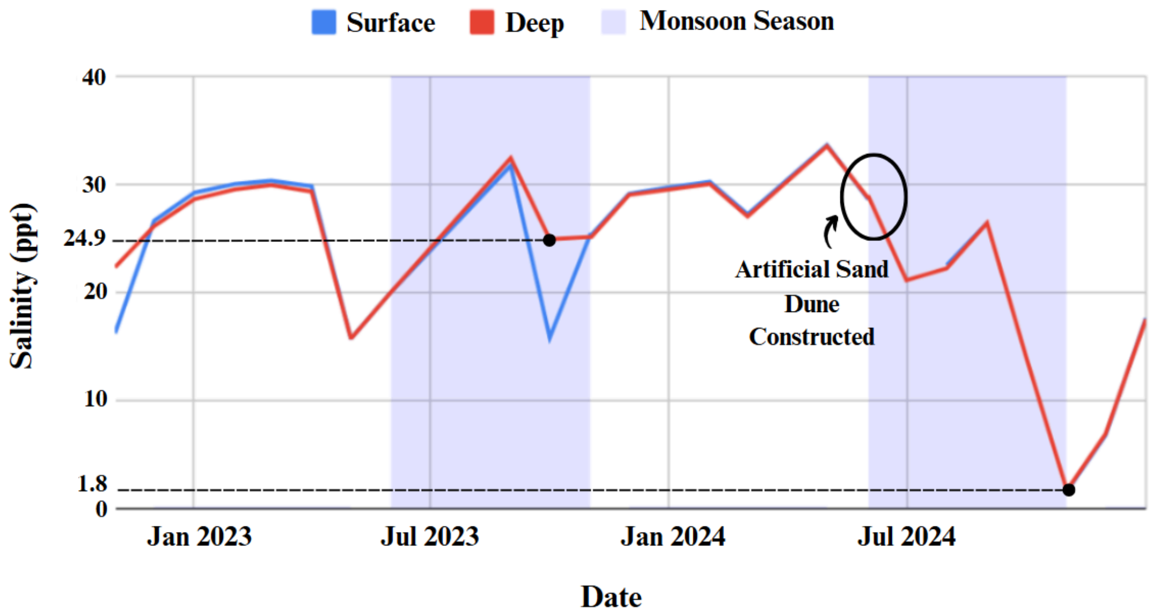
One of the ongoing ecosystem protection efforts by the Mrigadayavan Palace Foundation is the restriction of seawater from the grounds of the palace. There are currently two permanent barriers in place: a southern weir and watergate and a northern artificial sand dune. These both seemingly prevent the flow of seawater into the palace's waterways but have failed to fully address the issue of high water salinity. This is demonstrated in the relative water salinities on either side of these barriers, as well as in seasonal salinity changes. While salinity was high on both sides of the barriers, the water and soil on the sides nearest to the Mrigadayavan Palace were found to have lower salinity.

At the artificial sand dune, soil salinity was measured on the Mrigadayavan Palace and SIEP sides at similar distances from the water. The soil salinity on the palace side averaged 2.67 dS/m while the SIEP side averaged 3.81 dS/m. Similarly, water salinity on the SIEP side of the artificial sand dune (location W-11) was 31.4 ppt, compared to the 17.6 ppt on the palace side (location W-10), in the most recent measurements from January of 2025. The data from the weir area showed a similar trend, with soil and water salinity on the palace side averaging 2.33 dS/m (site 5) and 28.2 ppt (location W-3), respectively, relative to the 3.91 dS/m (site 4) and 31.2 ppt (location W-4) on the side directly exposed to saltwater influx from the jetty. This indicated that the barriers were leading to slightly improved salinity levels on the palace grounds.

The differences observed in seasonal salinity change following the installation of the northern sand dune in mid 2024 were most noticeable at location W-5, as shown in Figure 16. While there was no immediate observable effect on salinity levels after the artificial sand dune was constructed, the following monsoon season led salinity levels to decrease significantly farther and more steadily than previous seasons. The salinity measurements reached a low of 1.8 ppt in deep water compared to the previous monsoon season low of 24.9 ppt. However, once the monsoon season elapsed, salinity rose back towards its original state, reaching 17.5 ppt in January of 2025. Although this was still an improvement from January of the previous year, when the salinity was measured at 29.5 ppt. This illustrated how the presence of these barriers contributed to declines in salinity but did not entirely resolve the salinity issues.

Figure 16

Salinity Levels in Surface and Deep Water at Location W-5.



Note. The figure shows a graph of the historical surface and deep water salinities at site W-5 based on measurements provided by the Mrigadayavan Palace Foundation. Approximate monsoon seasons (May through October) are indicated by a darker background. For reference, high water salinity has been demonstrated to have negative effects on vegetation at concentrations above 0.5 ppt (*Measuring Salinity of Water*, 2016).

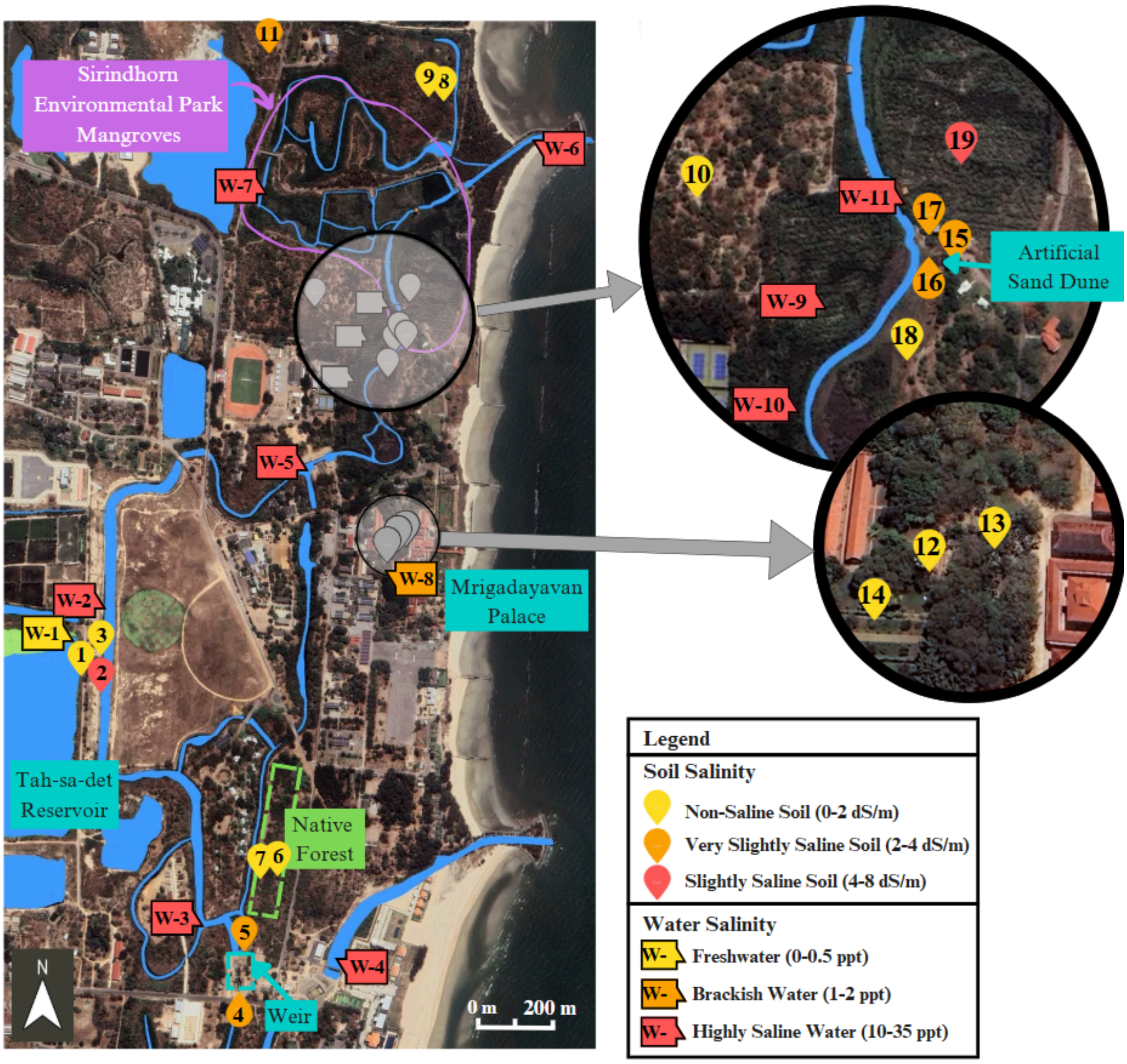
4.4 Finding 4: The Mrigadayavan Palace Area is in Need of Freshwater Influx

After consulting with both foundation and external experts, we identified the effect of water salinity on the environment surrounding the palace as a primary concern. As such, we conducted a large-scale analysis of the various sampling sites to determine the impact of water salinity on soil salinity, as well as water salinity trends over time. This demonstrated a direct correlation between higher water salinity levels and elevated soil salinity. In conjunction with seawater barriers, freshwater influx during monsoon season was also demonstrated to drastically decrease water salinity. For these reasons, we determined that the area surrounding the Mrigadayavan Palace was in need of freshwater influx.

One of the most pressing questions in protecting the palace's ecosystem was how the salinity of water sources affected that of the nearby soil. According to the Mrigadayavan expert and former Chulalongkorn University professor, Dr. Anond Snidvongs, as sandy soil is more porous than normal soil, it is easier for saltwater to inundate a sandy environment (personal communication, February 5, 2025). Likewise, Dr. Sirawat Udomsak, a Chulalongkorn University professor specializing in geological sedimentology, field geology, and marine geology, explained that seawater has the ability to quickly infiltrate porous soil (personal communication, January 24, 2025). Our own results illustrate and confirm these concerns, showing that soil was more saline in areas with nearby brackish water. Comparing our measurements of soil salinity and the foundation's most recent water salinity data, shown in Figure 17, we found a correlation between highly saline water sources and elevated soil salinity. This was most easily demonstrated around the artificial sand dune and weir, where the soil was found to be very slightly saline (2-4 dS/m) close to highly saline water (10-35 ppt). For reference, high water salinity has been demonstrated to have negative effects on vegetation at concentrations higher than 0.5 ppt (*Measuring Salinity of Water*, 2016). Site 2 was also determined to be slightly saline soil adjacent to highly saline water. An outlier in this location, site 3, was located higher up the bank from the source of water, meaning that likely the saline intrusion had not reached this far into the soil.

Figure 17

Comparison Map of January 2025 Results from Soil and Water Salinity Testing.

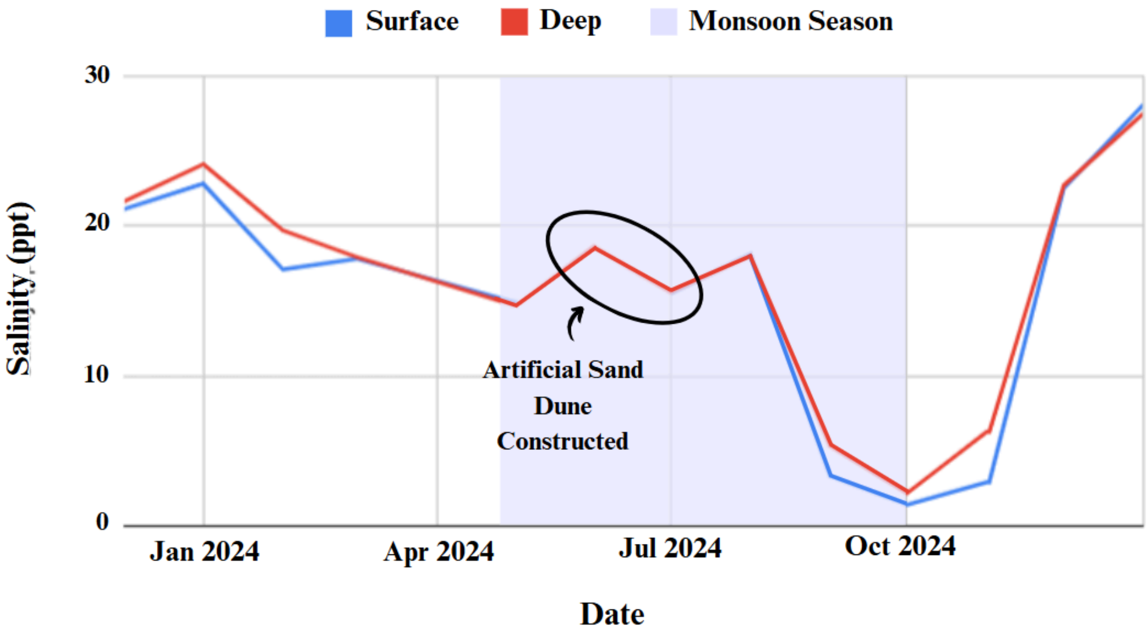


Note. The soil salinity values were compared to the classes adapted from the NRCS Soil Survey Handbook (USDA Natural Resources Conservation Service, 2011). The water salinity values were compared to the water salinity status chart in *Measuring Salinity of Water* (2016).

A critical factor in understanding water salinity around the palace was the influx of freshwater that comes with the monsoon season. We have previously noted that seawater barriers (the weir and artificial sand dune) implemented on the grounds led to declines in water salinity. However, an additional interesting comparison exists between the salinity amelioration observed inside the barriers during monsoon season and the trends outside of the barriers. Figures 18 and 19 show these trends following the construction of the artificial sand dune for site W-2 located within the barriers and site W-7 located outside, respectively. There is a noticeable trend of decreasing water salinity toward the end of the monsoon season in both graphs; however, site W-2 illustrates a much more drastic decline and slower recovery of elevated salinity following the end of monsoon season. This suggests that given a sustained freshwater recharge, the barriers will allow the palace waterways to maintain a lower average salinity than the areas directly exposed to saltwater inflow from the jetties.

Figure 18

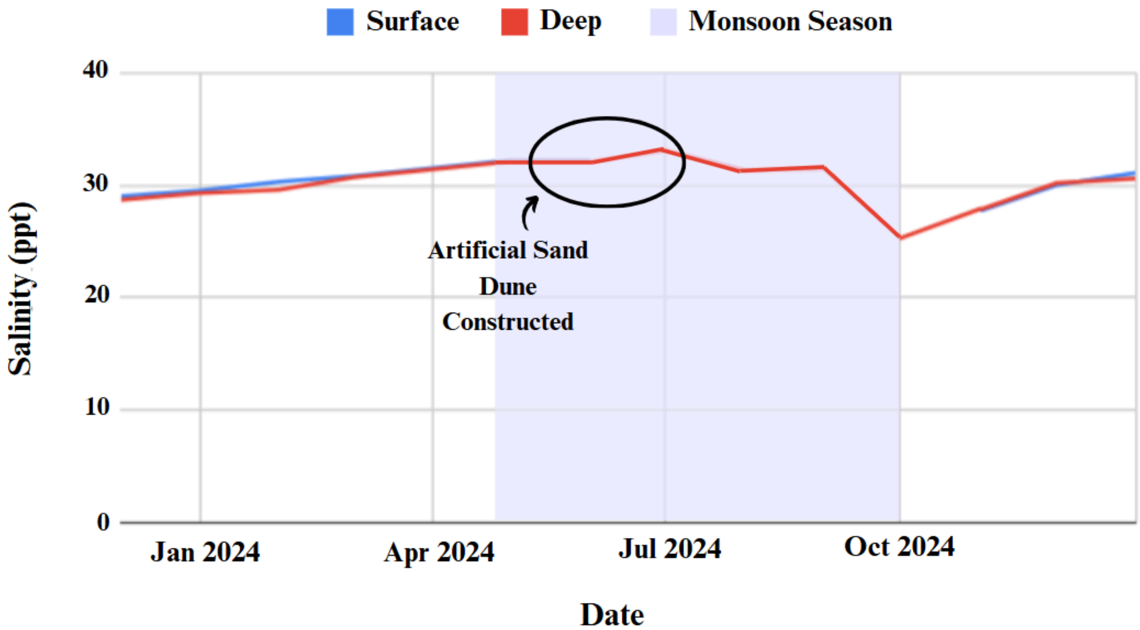
Salinity Levels in Surface and Deep Water at Site W-2, January 2024-January 2025.



Note. The figure shows a graph of the historical surface and deep water salinities at site W-2 obtained by the Mrigadayavan Palace Foundation. The approximate monsoon season is marked by a darker background. For reference, high water salinity has been demonstrated to have negative effects on vegetation at concentrations higher than 0.5 ppt (*Measuring Salinity of Water*, 2016).

Figure 19

Salinity Levels in Surface and Deep Water at Site W-7, January 2024-January 2025.



Note. The figure shows a graph of the historical surface and deep water salinities at site W-7 obtained by the Mrigadayavan Palace Foundation. The approximate monsoon season is marked by a darker background. For reference, high water salinity has been demonstrated to have negative effects on vegetation at concentrations higher than 0.5 ppt (*Measuring Salinity of Water*, 2016).

4.5 Limitations

This study faced several limitations to its scope and findings. The seven-week research period in Thailand, with only a few days spent at the Mrigadayavan Palace, restricted the quantity of observations that could be made. Given more time, we would have taken more soil measurements around the palace both at varying distances from sources of water and at varying depths to determine the extent of the saltwater intrusion into the soil. Additionally, our requests to speak with representatives from the SIEP and Rama VI Military Camp were declined, limiting our ability to gather insights from stakeholders in the area other than our sponsor. Lastly, as undergraduate students, we acknowledge our limited expertise in climate resilience and sustainable development, which led us to rely heavily on input from advisors and experts to inform our analysis.

Chapter 5: Recommendations & Conclusion

In this chapter, we developed five primary recommendations for the Mrigadayavan Palace Foundation as the most actionable steps that could be taken to achieve their restoration goals. These potential exploits were informed by our data-driven findings, consultations with experts, and archival research and aimed to help preserve a vital piece of Thailand's cultural and ecological heritage.

5.1 Recommendations Regarding Freshwater Influx

Based on the Kasetsart University report and our own findings, we recommend the use of freshwater recharge to reduce the salinity of the palace ecosystem. Given the sensitivity of the native plants to soil conditions, freshwater influx onto the palace grounds is critical to protecting the area from saltwater intrusion. Moreover, existing physical barriers should be kept in place, as they were determined to be an effective measure at reducing water salinity in the palace's waterways when combined with a consistent freshwater flow. In the case that these actions cannot be taken and a short-term solution is needed, a zeolite filter could be used to reduce salinity in key areas.

5.1.1 Artificial Freshwater Recharge Should Be Implemented to Reduce Water Salinity Levels

Our research strongly suggests that the native environment requires a low level of salinity, which can be achieved through regular freshwater influx. This process would involve using a slow and steady inflow of freshwater to push the saltwater out of the freshwater waterways or dilute the salinity.

Kasetsart University's report on freshwater recharge at the Mrigadayavan Palace ran several freshwater influx scenarios, which the foundation could use to inform their recharge strategies. One of these involved channeling 100,000-1,000,000 m^3 per year of additional freshwater into Tah-sa-det reservoir, allowing this water to flow into the palace's waterways and decrease the salinity (Kasetsart University, 2020). Groundwater recharge schemes discussed in this report could also be investigated by the foundation as potential strategies for addressing the saltwater intrusion issues.

In addition, Dr. Anond Snidvongs recommended releasing 400 m^3 daily (146,000 m^3 per year) from the Tah-sa-det reservoir to restore the freshwater on the grounds. This flow could be directed through the reservoir's irrigation canal. Our findings support this, although recharge could be prioritized during the dry season, as monsoon rainfall was shown to result in low salinity levels during the rainy season. This seasonal recharge could reduce the annual freshwater usage from approximately 146,000 m^3 to 84,400 m^3 yearly in the case that annual volume is a major concern.

5.1.2 Zeolite Filtering Should be Explored if Freshwater Recharge Cannot be Achieved

In the case that salinity remains high in the palace's waterways, we recommend the use of a small-scale zeolite filter in a location near to where elevated salinity issues persist. Zeolite is a naturally occurring mineral that can be used as a small-scale water filtering material. It has the ability to store salt in its structure due to its porous nature and ion exchange capabilities. This process involves exchanging a sodium (Na) ion with either calcium (Ca) or magnesium (Mg), therefore removing Na from the water and reducing the overall salinity (Sruthy et al., 2021). The construction of small-scale zeolite filters, as shown in Appendix E, requires natural zeolite (50-300 USD/metric ton or 1.7-10.2 baht/kg), a tank (price varies), sand (easily available), and geotextile fabric (25 baht/m^2) (Sruthy et al., 2021; Williams, 2024; Matiply, 2021).

5.2 Recommendations Moving Forward

As our project centered around research corroborating the efforts of the foundation to restore the native environment, one of the most important aspects to consider was areas where more robust data was needed. Thus, a critical component of our recommendations was identifying key areas where additional research and data collection are necessary to strengthen restoration efforts.

5.2.1 Trends Analyzed in This Report Should be Further Explored

Due to both our limited time frame in collecting soil measurements and the challenges of parsing the foundation's data, our analysis was fairly limited. Much more conclusive findings could be drawn by using the foundation's full set of data on water salinity over time. Pairing greater analysis with physical events such as water gate closure, sand dune installation, and monsoons could give much more definitive evidence of how these changes have affected the palace's water systems.

5.2.2 The Extent of Saltwater Intrusion Should be Tested Further

Given our meaningful results from minimal soil testing, we recommend a further set of tests to be conducted concerning the inland reach of salt from the waterways. This can be achieved by testing the electrical conductivity in incremental points closer inland from a saltwater source. Additionally, as our testing was limited to surface-level samples, it could be compelling to conduct a more thorough analysis of the groundwater and soil salinity around the palace. This would involve taking soil samples deeper underground to observe the extent of saline intrusion. While this would require the use of more expensive sampling methods, it would likely demonstrate more clearly how the salinity of the waterways has affected the local environment.

5.2.3 An Empirical Report on the Native Ecosystem Should be Used to Support the Foundation's Goals and Coordination Among Stakeholders

Based on our work, we believe that a holistic environmental report would be an effective way to communicate the native ecosystem's needs and characteristics. One of the primary issues the foundation faces appears to be coordination with other stakeholders in the area. We believe that organizing the foundation's specific issues and goals would be valuable in making forward progress. When working with the Border Patrol Police, definite evidence around the cost to maintain the local ecosystem and its ability to protect the coastline would likely be the most useful aspect of this. This report could also be used to facilitate more productive discussions with SIEP by focusing on practical solutions and compromises to specific issues, such as the health of the ecosystem, rather than the agenda of either organization.

5.3 Conclusion

Our project provided the Mrigadayavan Palace Foundation with information that supports its goal to restore native freshwater habitats. We produced evidence to support ecological conservation strategies through an analysis of soil composition, salinity levels, and vegetation distribution. Furthermore, our research demonstrated the complexities of ecological restoration and the need for new methods in preventing further degradation. This report aims not only to support short-term efforts but to inform the future restoration of native ecosystems and sustained conservation efforts in the region. Additionally, we had the opportunity to present our findings to the United Nations Development Programme Biodiversity Finance Initiative (UNDP-BIOFIN), helping them understand how preservation efforts around the palace have negatively impacted the native ecosystem (Figure 20). Through collaboration with the UNDP-BIOFIN, we hope that our findings and efforts will contribute to the preservation of the natural heritage of the Mrigadayavan Palace.

Figure 20

Group Photo of Our Team With Dr. Kitichate Sridith, Khun Klaomard Yipintsoi (Director of Mrigadayavan Foundation), and the UNDP Team.

Note. Photo by Dr. Panawan Vanaphuti

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Appendix

Appendix A. Electrical Conductivity Meter

In our soil salinity testing, we utilized a HANNA Electrical Conductivity Meter. The following describes information for use of this tool:

1) Setup mode can be accessed by removing the battery cover on the back and pressing the button for setup mode
2) The device can be turned on by pressing the ON/OFF button on the front
3) In setup mode several settings can be changed, including
    - Unit of conductivity measurement: mS/cm, dS/m, or µS/cm
    - Temperature: ℃ or ℉
4) Once the desired settings have been selected, the tool is easy to use
    - Ensure that the screen reads zero while entirely exposed to air. If it does not, press the ON/OFF button to zero the device
    - Identify a patch of soil that is not too rocky and push the point of the tool into the ground, ensuring that the black section of the tip is at least 2-3 centimeters below the surface
    - Press the ON/OFF button for the device to record a measurement

5) The tool can be turned off by holding the ON/OFF button for several seconds
6) The tool can be cleaned with distilled water and a tissue
7) The upper limit for salinity measurements is 4000 μS/cm (4.0 dS/m)

Appendix B. Interview Questions for Non-Foundation Experts in the Field

Question in English	**Question in Thai**
1. How does salinity impact vegetation?	1. ความเค็มของน้ำมีผลต่อพืช อย่างไร?
2. How can ecosystems as a whole be impacted by increases in water salinity?	2. ระบบนิเวศโดยรวมจะได้รับผล กระทบอย่างไรจากการเพิ่มขึ้น ของความเค็มของน้ำ?
3. How familiar are you with the Mrigadayavan Palace Foundation and their restoration efforts on the Mrigadayavan Palace?	3. คุณมีความคุ้นเคยกับมูลนิธิพระราชนิเวศน์มฤคทายวัน และกระบวนการในการฟื้นฟูพระราชนิเวศน์มากน้อยแค่ไหน?
4. What, in your opinion, should the Foundation do to address its issues with regards to water salinity?	4. ในความเห็นของคุณ มูลนิธิควรดำเนินการอะไรเพื่อแก้ไขปัญหาความเค็มของน้ำ?
5. What are the long-term consequences of jetty-induced erosion at adjacent beaches?	5. การก่อสร้างท่าเทียบเรือจะส่งผลให้เกิดการกัดเซาะชายหาดบริเวณใกล้เคียงในระยะยาวได้อย่างไร?
6. How do seasonal winds affect sand movement and deposition on the shoreline?	6. อิทธิพลของลมตามฤดูกาลส่งผลต่อการเคลื่อนที่และการสะสมตัวของทรายตามแนวชายฝั่งอย่างไรบ้าง?
7. What natural factors contribute to the formation of sand dunes along the coast?	7. ปัจจัยทางธรรมชาติใดบ้างที่มีส่วนทำให้เกิดสันทรายตามแนวชายฝั่ง?
8. What are the impacts of winter monsoon winds (Oct-Mar) and summer monsoon winds (Apr-Sep)?	8. ลมมรสุมฤดูหนาว (ต.ค. - มี.ค.) และลมมรสุมฤดูร้อน (เม.ย. - ก.ย.) ส่งผลกระทบอย่างไรบ้าง?

9. How does water salinity impact soil quality?	9. ความเค็มของน้ำส่งผลต่อ คุณภาพของดินอย่างไร?
10. Do you have any suggestions on ways to improve soil quality in areas affected by saltwater intrusion?	10. คุณมีข้อเสนอแนะเกี่ยวกับวิธีการปรับปรุงคุณภาพของดินในพื้นที่ ที่ได้รับผลกระทบจากการรุกล้ำ ของน้ำเค็มหรือไม่?

Appendix C. Interview Questions for Foundation Members

Question in English	**Question in Thai**
1. How successful, in your opinion, have previous restoration efforts been with restoring plant life?	1. ในความคิดเห็นของคุณ ความพยายามฟื้นฟูพืชในอดีตประสบ-ความสำเร็จมากน้อยเพียงใด?
2. How has vegetation changed on the Palace grounds since 1924?	2. พืชพรรณในบริเวณพระราชนิเวศน์เปลี่ยนแปลงไปอย่างไรตั้งแต่ปี พ.ศ. 2467?
3. How has the water salinity changed in recent years?	3. ช่วงไม่กี่ปีที่ผ่านมาความเค็มของน้ำมีการเปลี่ยนแปลงไปอย่างไรบ้าง?
4. What efforts has the Foundation overseen that you believe to be most helpful in achieving their goals?	4. ในความคิดเห็นของคุณ โปรเจคใดบ้างของมูลนิธิมีประโยชน์ต่อการบรรลุเป้าหมายการฟื้นฟูพระราชนิเวศน์มฤคทายวัน?
5. How impactful do you believe removing or filling the jetties would be in addressing the salinity issues?	5. คุณคิดว่าการรื้อถอนหรือถมปิดทางเข้าท่าเทียบเรือจะสามารถแก้ไขปัญหาความเค็มของน้ำได้มากน้อยเพียงใด?
6. How would you describe the native ecosystem at Mrigadayavan Palace prior to human intervention?	6. ระบบนิเวศธรรมชาติของพระราชนิเวศน์ที่ยังไม่มีแทรกแซงจากมนุษย์เป็นอย่างไร?

7. Are there any parts of protecting/restoring the grounds that you think are not being effectively communicated to other stakeholders/the surrounding community?	7. คุณคิดว่าพื้นที่ใดบ้าง ที่ได้รับการปกป้องหรือฟื้นฟู ผ่านการสื่อสารอย่างไม่มีประสิทธิภาพกับผู้มีส่วนได้ส่วนเสียหรือชุมชนบริเวณโดยรอบ?

Appendix D. Informed Consent Script

You are being asked to take part in a research study concerning the Mrigadayavan Palace restoration project, local salinity levels, and the impacts on local vegetation. This study hopes to provide useful recommendations to the Mrigadayavan Palace concerning the improvement of water quality and the health of plant life on the palace grounds. The results of this study will be published. This study is being conducted by a team of students from Worcester Polytechnic Institute and Chulalongkorn University. The principal investigator is the Mrigadayavan Palace Foundation. Questions about this study may be directed to the Coastal Restoration IQP-ISSP team at iqp.issp5@gmail.com. Questions or comments about your rights as a study participant may be directed to the Institutional Review Board Manager, Ruth McKeogh, at irb@wpi.edu or by phone at +1 (508)-831-6699. You may also direct these questions or comments to the Human Protection Administrator, Gabriel Johnson, at gjohnson@wpi.edu or by phone at +1 (508)-831-4989.

You have been selected to take part in this research due to your expertise in the relevant fields of geology or botany. Your participation is important to this research and we appreciate your taking time to help.

You will be asked a series of questions about the impacts of coastal structures and elevated salinity on vegetation diversity as well as some of your personal opinions on how elevated soil salinity can be addressed. These questions will take no longer than 30 minutes to answer and the risks associated with answering these questions are minimal.

Records of your participation in this study will be held confidential so far as permitted by law, unless you provide consent for your name to be published. However, the study investigators, the sponsor or its designee, and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board

(WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Your responses will be recorded, but will be kept confidential by the researchers, and no one outside of the research team will see or hear them. If at any point you wish to say something off the record you may ask for the recording device to be stopped.

Your participation is voluntary. You do not have to provide any information that you do not wish to provide, or answer any questions that you prefer not to answer. If, at any time, you decide not to continue, you may simply say so and the interview will be terminated. You do not give up any of your legal rights by agreeing to participate.

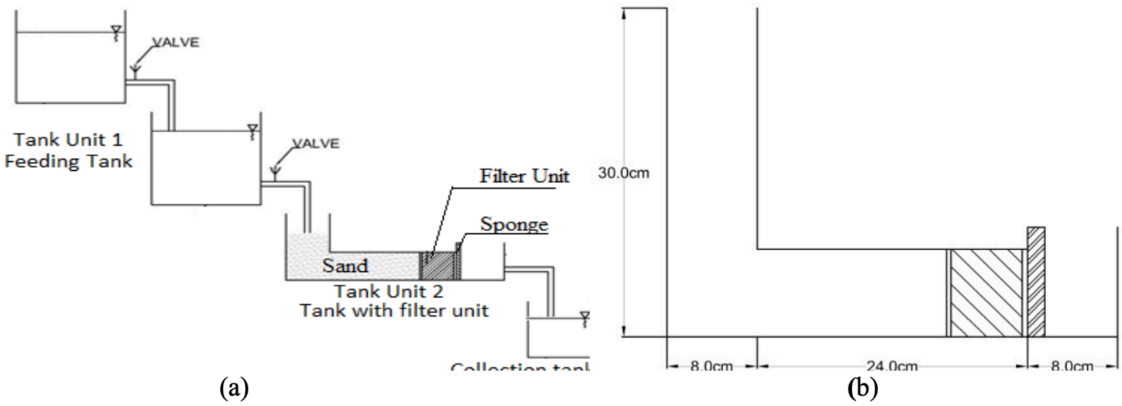
If you have any questions about your participation rights or the purpose of this study, you may ask them now.

By verbally confirming your intention to participate, you indicate that you have understood what is being asked of you, and that you consent to participate.

Appendix E. Additional Figures

Figure 21

The Construction of Small-Scale Zeolite Filters.



Note: (a) Schematic diagram of the experimental setup (b) L-shaped tank with filter unit Swale

Figure 22

Differential Settling Velocity Soil Composition Test.

Note. Also known as the jar test. The test had been going for about one hour when the photograph was taken.