Masters Program in Geospatial Technologies

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A geospatial approach for reducing uncertainty about the mitigation effect of seagrass on coastal erosion

A study case for the Greek coastline

by
Alonso Gonzalez

Master Dissertation presented as partial requirement for obtaining the
Master's Degree in Geospatial Technologies

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February, 2025

STATEMENT OF INTEGRITY

I declare that the work described in this document is my own and not from someone else. All the assistance I have received from other people is duly acknowledged and all the sources (published or not published) are referenced.

This work has not been previously evaluated or submitted to NOVA Information Management School or elsewhere. I further declare that I have fully acknowledged the Rules of Conduct and Code of Honor from the **NOVA Information Management School.**

Lisbon, January 24th 2025

Alonso Gonzalez

USE OF GENERATIVE ARTIFICIAL INTELLIGENCE

Task	No/Yes	AI Tools
Better understand issues related to the research	No	ChatGPT
Summarizing text from bibliography / resources	No	ChatGPT
Summarizing the method(s) used	No	ChatGPT
Translating text	No	ChatGPT
Grammar check	Yes	ChatGPT
Paraphrase or rewriting text from other people / resources	Yes	ChatGPT
Coding in R, Python, etc.	Yes	ChatGPT
Get help on a software	No	ChatGPT
Creating and editing images, maps, videos, etc.	No	ChatGPT
Data analysis	No	ChatGPT
Specify below other tasks not mentioned above:		
Getting relevant authors on literature	Yes	ChatGPT

DEDICATION

The responsibility of my education has been shared with my parents since I was a kid growing up in México, therefore also the achievements that this process will bring.

Mom and dad, this is yours, I'm forever grateful for your trust.

Thanks to my sister for laughing with me and to my brother for guiding me into new territories.

Thanks to the involved institutions and the patience of professors and staff, to the people I worked with along the way, and lastly to books, maps, bikes, friends and music.

Atentamente
Alonso

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Thanks to Sara and Nicolas for their assertive guide.

Chris and Sebastian for having a kind and big brain.

Geospatial Analysis on the Role of Seagrass Meadows in Coastal Dynamics: A Case Study of the Greek Coastline

Abstract

This thesis presents a methodology for assessing the role of seagrass meadows in mitigating coastal erosion through geospatial analysis. It leverages georeferenced data and long-term satellite imagery to explore the nuanced relationship between Posidonia oceanica and the eroding coastlines of Greece. The results of this analysis did not demonstrate a substantial numerical impact, highlighting the need for either a finer scale of analysis or a broader dataset to draw meaningful conclusions.

Keywords

Coastal erosion, seagrass, coastal dynamics, Greece, geospatial analysis

Sustainable Development Goals (SGD):

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Source: Nelson Krebs drone survey

Eroding Coastline
Agios Konstantinos, Samos
Greece, 2024

1. Introduction

Fifty seven percent of the Greek population lives along the country's coastline (*Polyzos et al, 2011*), *where twenty eight percent* of it is exposed to coastal erosion *(Karkani et al, 2023)*. The primary drivers of this phenomenon include sea level rise, storms, winds, nearshore currents, and soil composition (*Petrakis et al, 2014*). Specific conditions that make Greece particularly susceptible to coastal erosion include its coastal geomorphology, the average wave heights in the Aegean Sea, and the intense touristic pressure exerted on its 13,676 km shoreline (*Bird, 2010*) .

Greece heavily relies on coastal systems; as much as 18% of the country's GDP comes from services related to marine environments. Industries such as tourism, sea trade, and energy routes rank high among the country's economic priorities. According to the work of Paprotny et al., Greece ranks second in the European Union for projected GDP losses due to coastal erosion by 2100. It is estimated that some regions could lose nearly 4% of their GDP, with an overall national loss of approximately 2% (*Paprotny et al, 2021*) .

Data on Greece's expenditure for securing its coastal regions is scarce. There is no specific action plan or clear strategy for addressing the issue from official sources or authorities. A study conducted by Karkani et al. revealed a lack of widespread awareness of the problem among the Greek population. Surveys showed that 33% of respondents were unaware of the phenomenon, and 80% believed that authorities provided insufficient information about the issue (Karkani, 2023) .

Vegetation-based approaches to coastal protection, often categorized as "nature-based solutions," have increasingly gained traction as “soft” alternatives to conventional infrastructure-focused solutions. Traditional methods, such as sediment restoration and the use of groins to stabilize shorelines, are being supplemented by these ecological strategies.

Early mentions of nature-based approaches can be found in the work of the US Army Corps of Engineers during the early 1970s. Experiments with Spartina alterniflora seagrass were conducted to observe its ability to mitigate erosion along the banks of Cape Lookout National Park in North Carolina (Woodhouse, 1974).

Although the results of these experiments did not yield positive outcomes, the agency's research on coastal dynamics became highly influential in later decades. Specifically, the 1974 paper Application of ERTS-1 Imagery in Coastal Studies laid the foundation for using optical imagery over extended periods to study coastal systems (Magoon, 1976).

1.1 Historic review

Coastline Changes: A Global Review, written in the mid-1980s, laid the groundwork for some of the earliest quantitative criteria for classifying eroding, stable, and accreting shorelines. While these classifications have been widely adopted, they have largely remained static, often failing to account for the evolving challenges posed by climate change or the nuanced characteristics of diverse geographic contexts (Bird, 1985).

Building on these foundational ideas, Luciana S. Esteves explored their practical application in her seminal paper, **The Problem of Critically Eroded Areas (CEA): An Evaluation of Florida Beaches.** Her work exemplifies a region-scale approach that integrates these longstanding principles, demonstrating their continued relevance in contemporary contexts (Esteves et al, 1984) .

In Greece, the challenge of coastal erosion is further compounded by unique ecological and environmental factors, including the role of **Posidonia oceanica meadows**. These underwater plants, native to the Mediterranean Sea, not only function as carbon sinks but also serve as natural barriers that help mitigate erosion by stabilizing sediments and dissipating wave energy. Despite their ecological importance, the integration of such factors into existing coastal management frameworks remains limited, underscoring the need for updated methodologies that address Greece's specific geographic and climatic conditions (Vasarri et al, 2021).

The findings of this research aim to inform future methodologies by examining historical approaches to coastal erosion whilst integrating contemporary resources. This strategy has the potential to influence coastal engineering practices while prioritizing the preservation of marine environments, with a particular focus on the role of Posidonia oceanica.

This diagram summarizes the milestones that have significantly influenced research on the role of seagrass environments in mitigating coastal erosion.

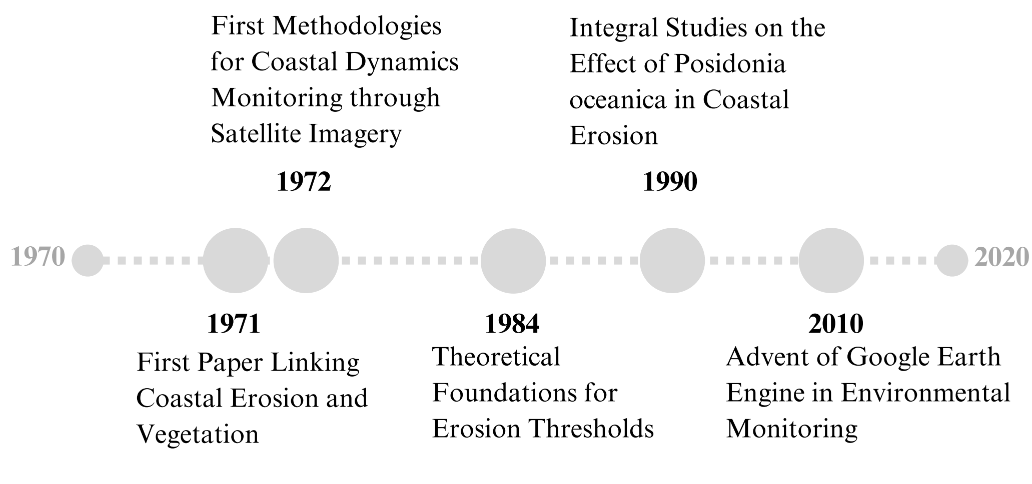


Figure 1. Milestones on the study of coastal dynamics and seagrass meadows, (Self made)

*Posidonia oceanica i*s the only endemic seagrass species of the Mediterranean Sea and forms dense and extensive green meadows. These environments provide biomass, participate in the ocean's oxygenating cycles, and serve as major CO_2 sinks. In addition to their ecological role, P. oceanica meadows create habitats for hundreds of species, supporting biodiversity and maintaining ecosystem stability. These benefits have influenced its recognition as a priority habitat type for conservation and management by the European Environment Agency (EEA).

Beyond their ecological contributions, P. oceanica meadows play a crucial role in coastal protection. Their complex root and rhizome network stabilizes sediments, reducing seabed erosion and buffering the impacts of waves and currents. However, their influence extends beyond the underwater environment. This species sheds its leaves in autumn, creating large deposits of litter in the surf zone and forming substantial accumulations on adjacent beaches, known as banquettes. These deposits can range from a few centimeters to several meters in thickness, forming wedge and layered structures.

Some researchers highlight the importance of these banquettes in protecting sandy beaches by dissipating wave energy and reducing erosion. Others, however, argue that this effect is minimal or site-dependent. The debate surrounding P. oceanica's role in coastal erosion management remains active, underscoring the need for further research.

This thesis aims to test the effects of large systems of posidonia oceanica meadows on the records of coastal erosion of Greece by overlaying the polygons and comparing the area lost to the action of waves to the potential protection that the structures mentioned above can provide. The regional and large scale approach is the definying feature of this analysis, by pulling from a large enough dataset the autor expects to find a significant measurement of the relation or contribute to the body of work that leans on the direction of the minimal, site-dependant or outright dismiss the notion of a protective mechanism against coastal erosion.

Another contributing factor to the appeal of this thesis is the fact that firsthand observations and impressions of these environments were collected during a two-month fieldwork on the island of Samos. This direct engagement allowed for a detailed examination of the island's highly variable coastal dynamics, shaped by the diversity of rock formations and the contrasting erosion patterns observed across different regions. The disparities in erosion rates accentuate the reason to be on the ground as preparation for the formal stages of the work. This research, therefore, benefits from both large scale approach (Greece) of the country data and specific field-based insights that contribute to a more comprehensive understanding of coastal trends, using Samos as a geographical laboratory to extrapolate.

1.2 Research question

The primary research question guiding this thesis is: **Can Posidonia oceanica mitigate erosion along the Greek coastlines?** This inquiry seeks to investigate the relationship between the presence of this important marine vegetation and its potential to reduce coastal erosion rates in the region. Overall there's a body of work that link them in lab environments and bay level studies but scarce research has been directed towards its analysis on a regional scale.

Despite increasing recognition of marine vegetation's role in coastal dynamics, few studies have quantitatively measured the effect of Posidonia oceanica on erosion, particularly at the regional level. This research will fill this gap by providing data on the influence of seagrass meadows on coastal erosion rates in Greece, contributing to a more comprehensive understanding of marine vegetation's role in coastal protection. **The research unfold in three key phases:**

1. **Field work:** From August to October 2024, an internship with the Archipelagos Institute for Marine Conservation, based in Samos, Greece, under the supervision of Tim Grandjean, PhD. Activities included:
    - Conducting drone surveys of coastal areas.
    - Using kayaks to carry out bathymetric profile surveys.
    - Collecting coastal measurement data for analysis.
2. **Geospatial Processes and Data Analysis:** The data collected in the field will be processed through geospatial analysis, including satellite imagery and remote sensing techniques. Mapping Posidonia oceanica distribution along the Greek coastline will be a key component, alongside measuring coastal erosion rates.
3. **Discussion of Results**: The final phase involved analyzing the relationship between Posidonia oceanica presence and coastal erosion mitigation trough discussions with the thesis supervisors at NOVA Universidade.

Thesis overview

Research question
- Can Posidonia oceanica mitigate erosion on Greek coastlines?
- What is the numerical relationship that measures this effect?

Research gap
- The body of work that measures the effect of marine vegetation on a regional scale is scarce.
- Coastal erosion rates have remained the same despite the fact that climate change has accelerated and increased them.

Methodology

Three phase analysis:
a) Internship at Archipelagos Institute for Marine Conservation
b) Geospatial processes and discussion of results
c) Thesis seminar

Intership agreement:
- Archipelagos Institute for Marine conservation
    - Where: Samos, Greece
    - When: Aug - Oct 2024
    - Point of Contact: Tim Grandjean PhD.

Field work activities:
- Drone survey of coastal areas
- Kayak surveys for bathymetric profiles
- Geospatial analysis of coastal measurements
- Mapping Posidonia oceanica through remote sensing

Expected outcomes:
- Quantitative Analysis of Posidonia oceanica's Effect on Erosion
- Guiding Coastal Management in Erosion-Prone Regions

Figure 2. Thesis overview

1.3 Objectives and strategy

The research question will be explored mainly trough four objectives:

- Finding out what's the numerical relation between posidonia oceanica and coastal erosion.
- Contribute to the body of work that either claim seagrass meadows do not contribute or mitigate coastal erosion and frame my results under this position.
- Take advantage of the field work phase of my thesis and leverage the knowledge to **reduce the uncertainty** surrounding the influence of seagrass on coastal erosion in the body of work or find what are scientists refering when they say that the role of seagrass in coastal dynamics is *nuanced or place specific*.
- Generate a discussion around the evolving nature of erosion rates in the contexts of the growing preassure on coastal environments posed by climate change.

To achieve these objectives the methodology will create a geospatial overlay methodology to get an initial value of relation that serves as a benchmark upon which observe what happens when parametric changes are performed on the database, erosion rates and the geospatial scale.

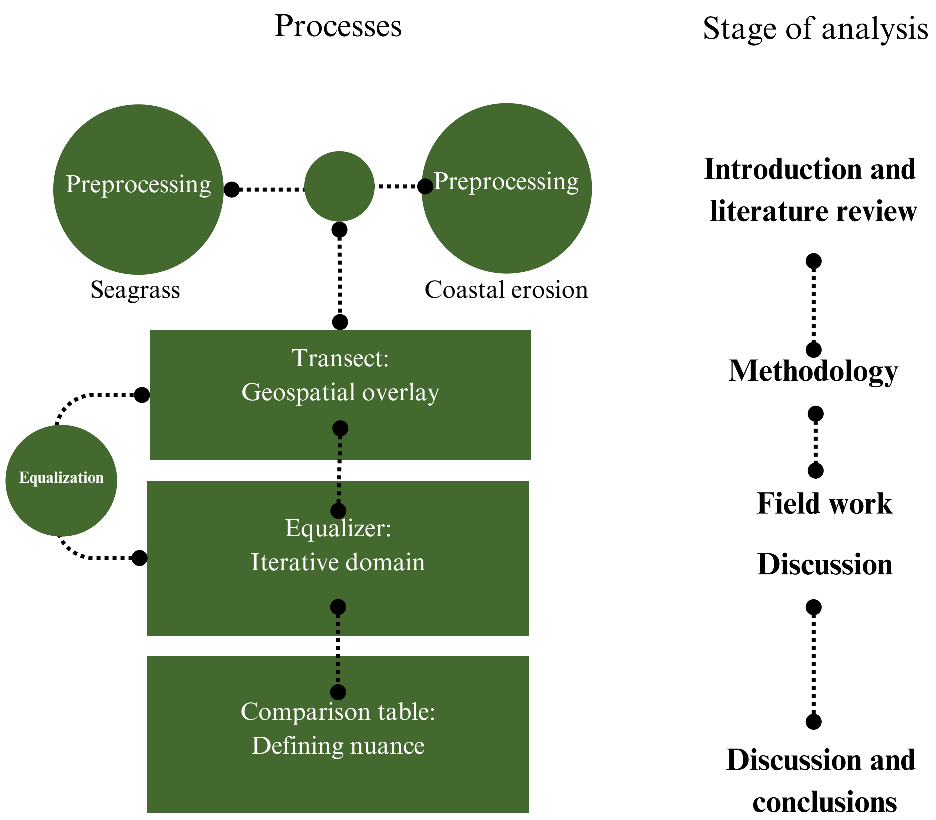


Figure 3. Processes and stage of analysis

2.Literature review

The following diagram expresses the structure of this literature review and its implementation, starting with general concept questions, followed by theoretical applications, and concluding with specific questions about the interpretation of results, placing them in the context of the overall body of work addressing coastal dynamics through environmental mitigation strategies.

General questions **Conceptual Questions**	Familiarization with the concepts related to coastal dynamics and the application of geotechnology in its analysis
Application questions **Theory applications**	How do specialists translate knowledge of coastal dynamics and model the various aspects influencing erosion events?
Specific questions **Practical Questions**	Specific questions derived from running an initial model to place the results in the context of other researchers' work.

Figure 4. Conceptual Framework for the Literature Review

As the analysis progressed, it became evident that the questions regarding the second and third sections held significant relevance in making sense of the results and informing the discussion. The questions from the first section helped during the conception of the research and in identifying the gaps that needed to be addressed.

Preliminary definitions: the shoreline and its fuzzy terms

> *Though strictly defined as the intersection of water and land surfaces, for practical purposes, the dynamic nature of this boundary and its dependence on the temporal and spatial scale at which it is being considered results in the use of a range of shoreline indicators.*
>
> *Boak, (2005)*

Simply put, the shoreline is the boundary where land meets water. However, this definition becomes complex due to the dynamic nature of coastlines, shaped by tides, waves, and other environmental processes. For the purposes of this study, the shoreline will be defined as the interface separating water features from land features, identified using remote sensing techniques. While this definition oversimplifies the complexity surrounding the concept of the shoreline (not even considering the more intricate discussions around scales and their fractal nature), it allows us to proceed with modeling the phenomenon.

In the paper Coastal Erosion Studies, the authors frame the occurrence of coastal erosion as the process where wind, waves, and longshore currents move sand from the shore and deposit it elsewhere over a given period of time. The sand can be relocated to another beach, to the deeper ocean floor, into an ocean trench, or onto the landside of a dune. This inherent complexity of the problem highlights the need for a dynamic approach when modeling it, one that incorporates both the spatial and temporal dimensions of the shoreline as changing features. This perspective ties our observations to the understanding that coastal erosion is an ongoing phenomenon that must be considered in relation to both the future and the past.

The first question addressed during this literature review concerns the limits and considerations of what constitutes erosion:
How do we differentiate between normal erosion and when should we raise awareness about this phenomenon?

One of the key insights that becomes increasingly important as the study develops is the ability to accurately determine when erosion is occurring and how to define the boundaries of normal coastal behavior. As Dionysios Apostolopoulos puts it in his seminal work on GIS applications to coastal dynamics, "Understanding the thresholds of natural variability in coastal systems is crucial for distinguishing between regular processes and those that may indicate a significant shift or risk." (Apostolopoulos, 2021). (This statement emphasizes the challenge of setting clear criteria for when coastal erosion should be considered a concern, requiring a nuanced understanding of both natural variability and potentially harmful deviations from it.

> *" As coastline is a dynamic environment and it's profile can very easily change from coast to coast continually, there is not one and only indicator which can match to all types of coasts.*
> *Indicators that measure the evolution and change of the coastline should be accurate and describe the timeless evolution of the area as well as the natural processes that have taken place"*
>
> *(Apostolopoulos, 2021)*

Our analysis used the most common approach out there: Long term, based on optical satellite imagery and implemented trough NWDI indexes for the differentiation of water/coast. This path was taken to assure a wide pool of research to draw upon:

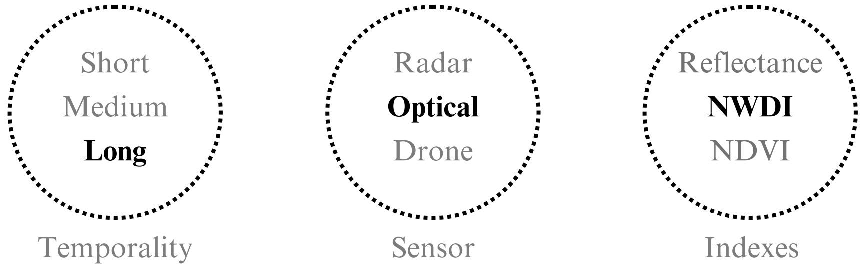


Figure 5. The Research Context of this thesis in Coastal Erosion Studies

Insights from research on coastal erosion rates:

- Most of the research reviewed in the initial phases of this thesis relied on the classification first proposed by Eric Bird in his seminal work *Coastline Changes: A Global Review.*
- This classification has been widely adopted with little consideration given to variations in the nature of specific environments. Two key considerations need to be taken into account:
    - Recent research shows that erosion rates in the literature lag behind what is observed in nature. In the early 1980s, normal rates were considered 0 to -0.5 m/year, but studies in the Pacific now suggest these are mild compared to current trends. For example, projections for Hawaii show that by 2050, 92% of shorelines could retreat 1 to 24 m, and by 2100, 96% may retreat 4 to 60 m. This equates to recession rates of 0.5 to 1.2 m/year, far exceeding historical norms and highlighting the urgent need for adaptive coastal management. (Anderson, 2015).
- Regarding European Standards: **Eurosion** is a program that consolidates the knowledge of various agencies across Europe to study coastal erosion. With the aim of providing a guide to inform policymakers about the state of their coastlines, the program introduced a distinction between stable and eroding beaches across the continent. However, *no specific numerical thresholds were established*. The methodology focuses on offering a consistent and homogeneous description of the European coastline, enabling comparisons and assessments on a continental scale. The study justifies the absence of numerical thresholds as a way to allow flexibility, accommodating the diverse coastal dynamics found in different regions (EUROSION, nd).

In conclusion, the factors defining the presence or absence of erosion were established by researchers with different environments in mind, and evidence has shown that trends tend to shift every two decades or so in terms of what constitutes mild or severe erosion. This is one aspect of the research that must be scrutinized and considered very carefully.

How do oceanographers account for the impact of seagrass in coastal dynamics?

This question is thoroughly addressed in Barbara Ondivela's paper The Role of Seagrasses in Coastal Protection in a Changing Climate, where she succinctly summarizes the state of knowledge about Posidonia oceanica's role in coastal management.

> *"The role of seagrass is very nuanced and it cannot be overestimated by saying that it mitigates erosion in every scenario or location."*
>
> *(Ondiviela, 2013)*

From the literature review, it is observed that most studies on seagrass properties for coastal protection are conducted in experimental lab settings. Tests that recreate soil columns and examine water interaction effects are often condensed into damping coefficients. One such experiment has shown that Posidonia oceanica can reduce the effect of waves on soil by 70% (Infantes, 2022).

Upon further inspection of the literature it became evident that there's not a unified methodology or benchmark statistical measurement linking posidonia oceanica to coastal dynamics, in addition the problem presents a high scale variability across the range of studies. The following insights were gathered during this stage of the thesis:

- The studies that offer an statistical measurement of the relation are perform on high-precision scenarios and highly controlled environments, conditions that are impossible to extrapolate to regional scales.
- There is insufficient geospatial information at the regional scale with the necessary spatial resolution to feed the parameters required for the models to run successfully.
- The only models that operate at a regional scale are high-precision analyses of bay areas, which are categorized as mid-size analyses.

Given this panorama: **How are geotechnologies being used to study the relationship between seagrass and coastal erosion?**

Currently, there is a limited number of studies focused on the regional impact of **Posidonia oceanica,** aside from the experiment-based approach mentioned earlier. While there is a well-documented understanding of the issue, no significant efforts have been made by the geospatial community to develop methods for systematically linking both aspects of the problem in large-scale projects.

Some of the insights gathered from this exercise include:

- Overall, there is a lack of research on the specific mathematical relationships linking seagrass and coastal dynamics at a large scale, in contrast to the prominent lab-based approaches.
- There is no clear path for scaling the knowledge generated in lab studies, particularly regarding methodologies for energy damping and subsequent studies on wave energy reduction. These studies generally agree that the rigidity of Posidonia oceanica leaves is the key characteristic responsible for its ability to mitigate wave energy and sediment deposition.

- Papers such as “Sandy Coastlines Under Threat of Erosion” are excellent examples of methodologies that expand the study of coastal erosion by integrating lab-based methods into global analyses (Vousdoukas, 2020). These studies made it possible to apply equations governing coastal erosion beyond experiments by statistically reviewing how sea-level rise trends could amplify the problem. The data used for erosion analysis relies on a common dataset, similar to the one used in our study. Although this is a promising approach, there are methodological gaps that could be addressed by leveraging spatial data and highlighting resources developed by geoscientists.
- A paper similar to this thesis at the regional scale is “Suitable Areas for Seagrass Restoration in the Mediterranean through a Multiple Criteria Decision Analysis (MCDA)”. While this paper presents an interesting approach, it focuses on ranking the characteristics that support seagrass reproduction at a regional scale by integrating parameters such as depth, temperature, and salinity. The goal is to define suitable areas for the reintroduction of seagrass environments (Derak, 2023).

The following diagram resumes the insights gathered from this survey in a more general way.

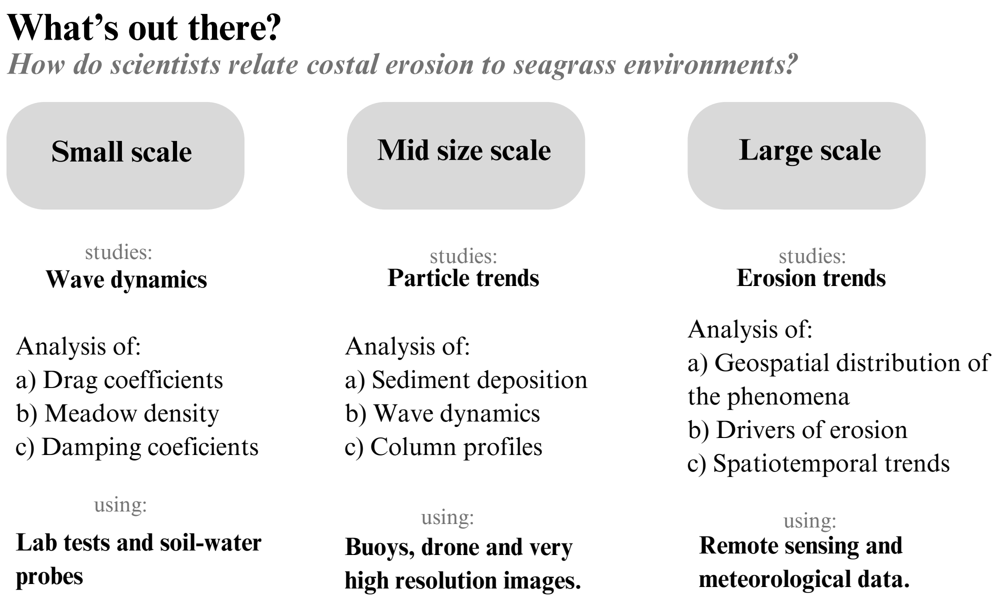


Figure 6. Scale of analysis and prominent methodologies on coastal dynamics

Bibliography metrics

A quick review of the number of publications related to coastal erosion and seagrass, particularly *Posidonia oceanica*, revealed that only a small proportion of the literature addresses the relationship between both phenomena.

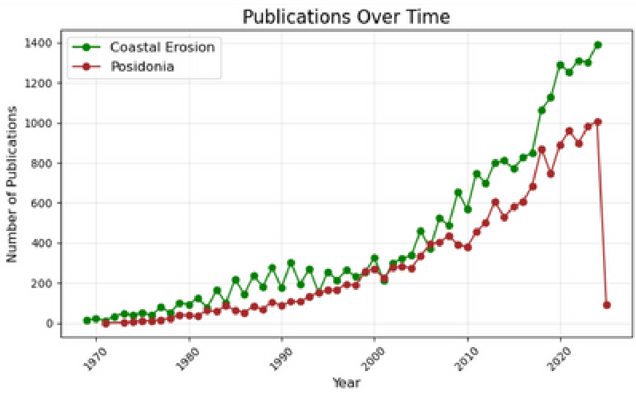
2.1 Bibliometrics

Table 1 Papers count based on keyword

Keyword	**Results**
Coastal erosion	85, 984
Posidonia Oceanica	3,599
Seagrass mapping	2,979
Coastal erosion and seagrass	4,056
Coastal erosion and posidonia oceanica	765

Throughout this section, we explore the context and scientific trends surrounding coastal erosion and its implications for vegetation.

How extensively have our subjects been explored in scientific research?



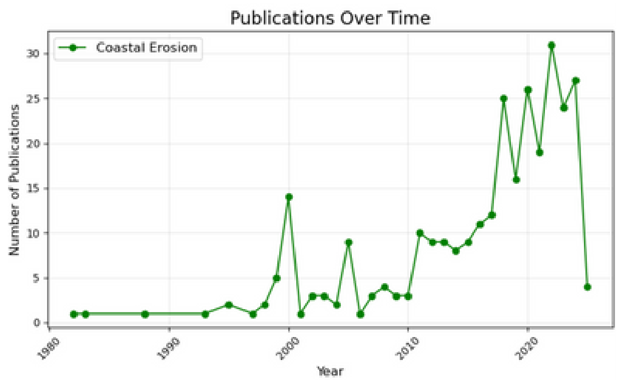
Seagrass and coastal erosion presence

keynotes:

1. *coastal + erosion*
2. *seagrass*

There is an ongoing production of papers on both of our topics.

source: Scopus



Seagrass relation to coastal erosion

keynotes:

1. *coastal + erosion + seagrass*

source: Scopus

Figure 7. Publications over time based on keyword search in scopus

What happened during those peak periods of publication?

- The 1980s marked the decade when the relationship between coastal erosion and seagrass was first studied.
- A trend towards softer approaches to coastal erosion management emerged in the 2000s, exemplified by the Integrated Coastal Zone Management (ICZM) framework from the EU.
- In 2010, the United Nations called for greater attention to the conservation and restoration of marine ecosystems, including seagrasses.
- The adoption of Earth Engine as a source of satellite imagery led to the development of various methodologies for detecting seagrass environments. Notable examples include the NDVI, Seagrass Index (SI), and the Ratio of Green to Red Reflectance (RGR).

Posidonia oceanica grows throughout the Mediterranean. The following chart highlights the countries with the highest output of soft approaches to coastal erosion. The Royal Netherlands Institute for Sea Research is the institution that has produced the greatest number of papers, likely due to its involvement in the large-scale project The Sand Motor (Zandmotor). This sand nourishment project, implemented in 2011, required extensive research to assess its success.

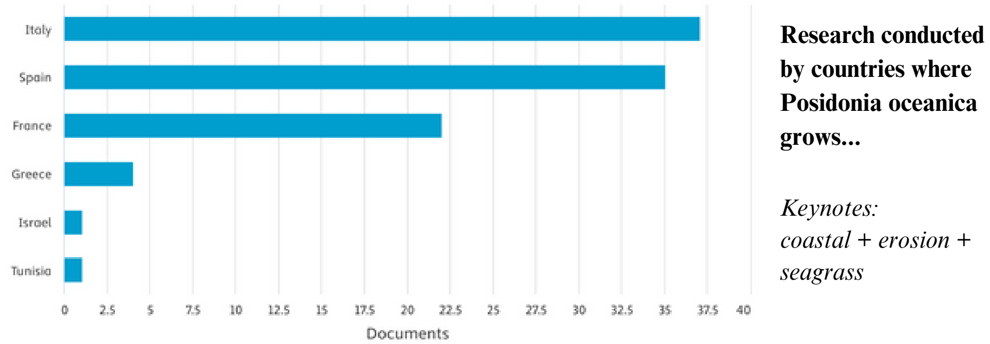


Figure 8. Publications from countries where posidonia oceanica grows

PRISMA diagram:

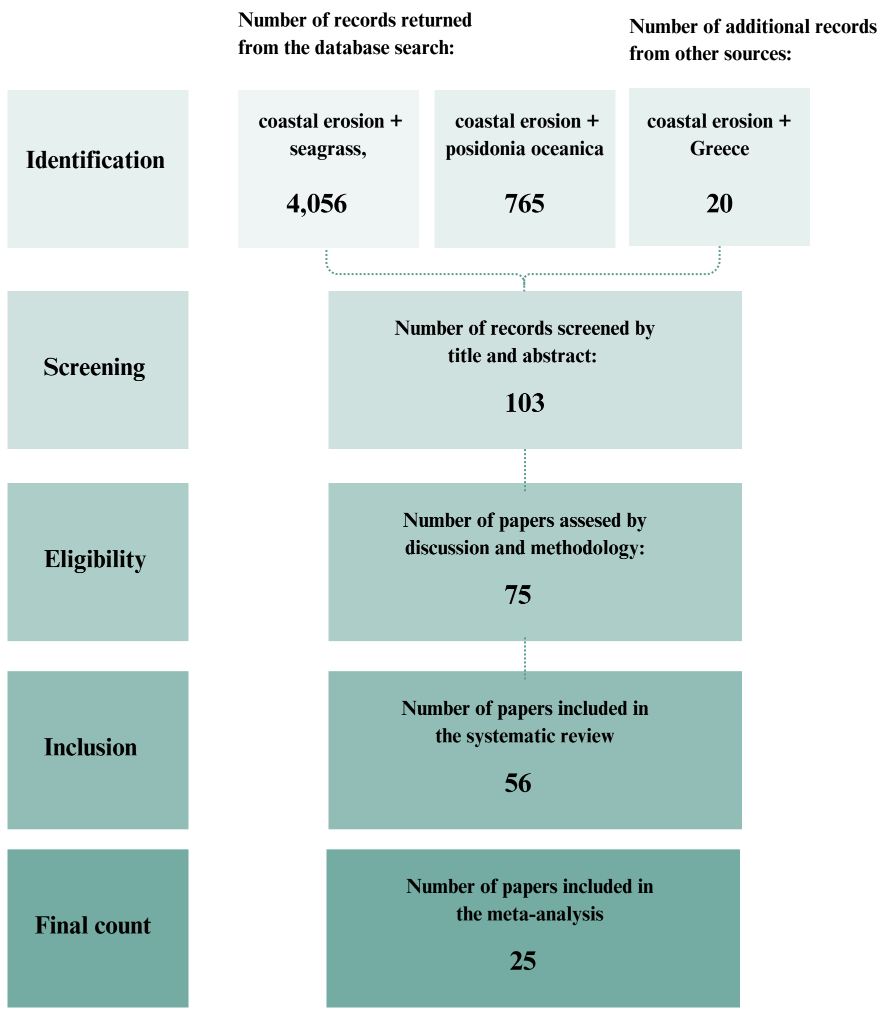


Figure 9. PRISMA Diagram

3. Methodology

3.1.1 The principles behind Shoreline Monitor

Shoreline Monitor is a project developed by **TU Delft** and the company **Deltares** that detects changes in the coastline by measuring shoreline movement in meters per year using remote sensing technology in Google Earth Engine, with a spatial resolution of *350 meters.* The dataset, comprising *24,371 points* distributed across Greece, is part of a global-scale assessment of sandy shoreline dynamics conducted through a fully automated analysis of *33 years (1984–2016).*

The database use the methodology initially described in the work of Hagenaars, et al. described in the paper: *On the accuracy of automated shoreline detection derived from Satellite imagery: A case study of the Sand Motor mega-scale nourishment* published in 2017 at the Coastal Engineering journal (Luijendijk, 2018) .

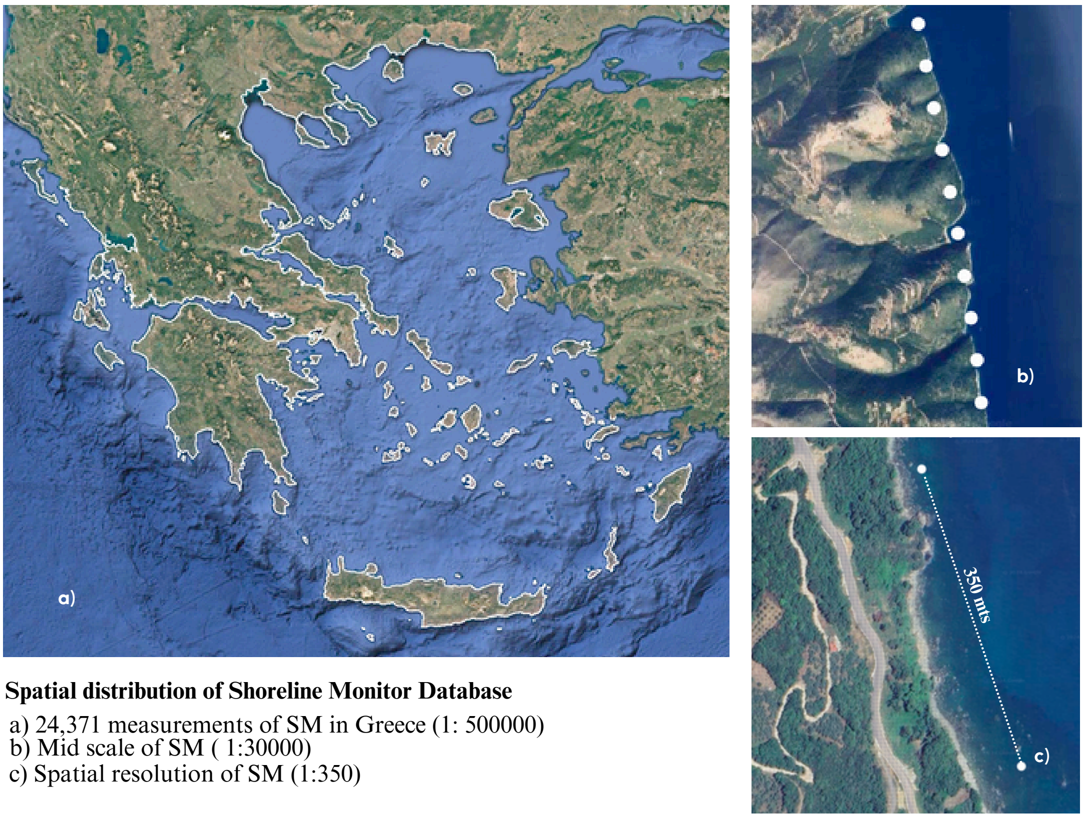


Figure 10. Spatial resolution and coverage of Shoreline Monitor, (Luijendijk et al, 2018)

The work of Shoreline Monitor is a byproduct of the technique known as Satellite-**Based Shoreline Detection (SDS),** which has been increasingly used by coastal managers. This trend is documented by Vos et al., who mapped the development of SDS methodologies leveraging Earth Engine.

> *The field's rapid progress has come in the form of approximately 40 new remote sensing algorithms that map shorelines from multispectral satellite imagery.*
>
> *(Vos , 2023).*

The database was created using the **Normalized Difference Water Index (NDWI),** calculated as the difference between the NIR and Green bands, and reproduced across the available set of images at each point between the **1984 and 2016** time period. Considering that each transect/point is spaced **350 meters apart**, it is evident that this global analysis of coastal dynamics was only made possible through the computational flexibility provided by Earth Engine.

Additionally, the paper employs the buffer overlay methodology proposed by Goodchild and Hunter to assess the positional accuracy of digitized linear features, which overall enhances confidence in the results obtained in this work (Goodchild et al, 1997).

The following diagram illustrates an example of the process followed by the authors to derive the coastline. It also highlights how erosion is visibly detectable without the need for further procedures in cases where change rates are high, as indicated by the gray area in the diagram below (e) .

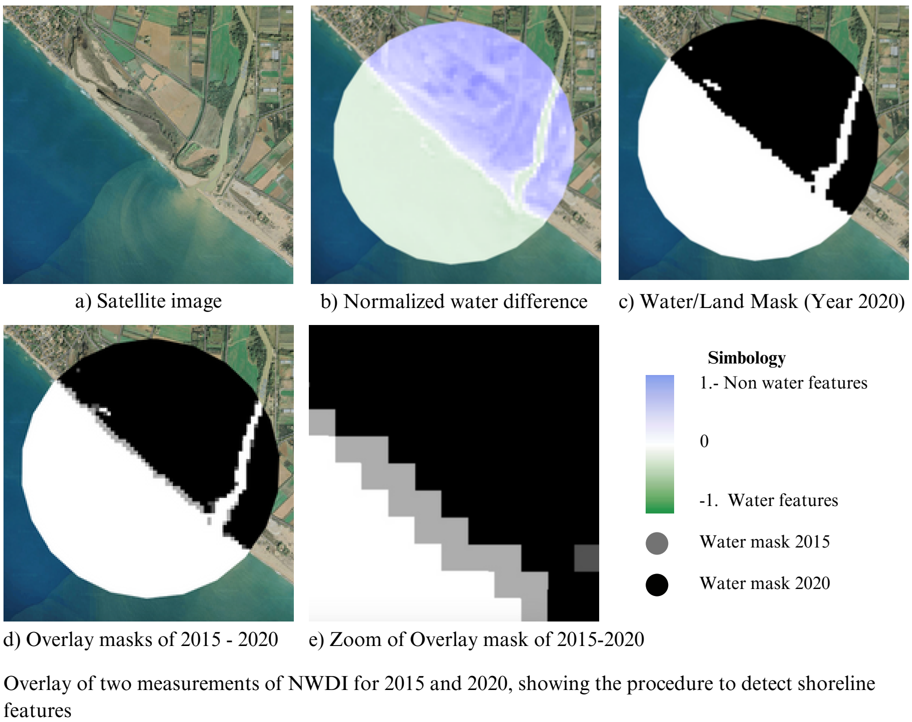
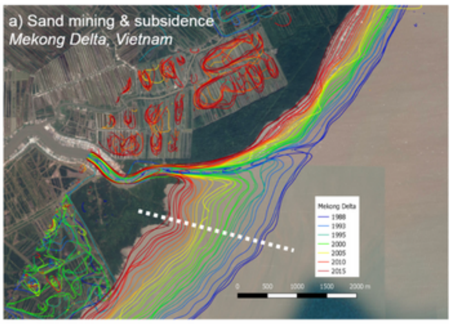


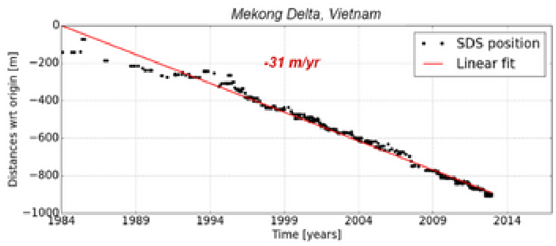
Figure 11. NDWI methodology example, (Luijendijk, 2018)

After this process is carried out for all available images in the Earth Engine catalog for the period of analysis, a **baseline shoreline** is defined. This baseline corresponds to the first image of the satellite mission (Sentinel-2). Using this baseline, the distance of each shoreline relative to the baseline is computed and plotted on a graph. This graph is then used to derive the ordinary least squares (OLS) equation, which describes the change rate factor by calculating the number of meters eroded over time.

In the image below and example of the process is presented, this diagram was taken from the paper of Luijendijk et al.:



Set of shorelines obtained, blue represents the oldest (baseline) position, and indicates the current state.



Ordinary least squares linear regression to obtain value of **changerate**

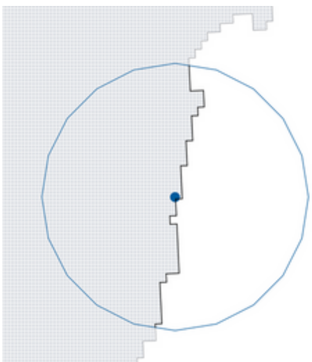
Figure 12. Set of shorelines obtained and their respective linear regression , (Luijendijk, 2018)

The results of the attribute **"change rate"** can be either positive or negative. Negative values indicate the coastline retreating inland, representing **coastal erosion**, while positive values indicate the deposition of sand particles, which increases the shoreline area—a process known as **accretion**. The dataset classifies the results of the algorithm into categories based on the behavior of the coastline. This classification was initially introduced by *Eric Bird* in the mid-1980s and subsequently implemented by the authors of this dataset.

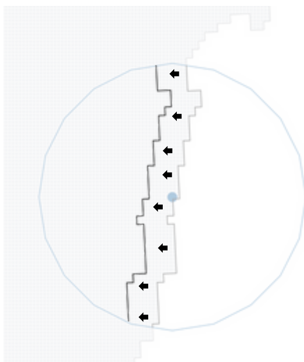
Table 2. Thresholds of coastal behavior (Bird, 1985):

a) Accretion: > 0.5 m/yr
b) Stable: -0.5 to 0.5 m/yr
c) Erosion: -1 to -0.5 m/yr
d) Intense erosion: -3 to -1m/yr
e) Extreme erosion: <-5 m/yr

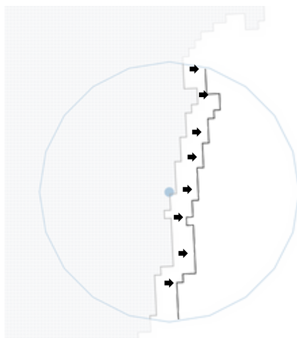
These values were also applied in this thesis, and their limits will be explored further in the discussion of the results. The following diagram depicts a representation of this behavior.



Stable coastline : Change rates values between **-0.5 to 0.5 mts/yr**



Eroding coastline: Change rates values below **-0.5 to 8.25 mts/yr**



Accreting coastline: Change rates values over **0.5 mts /yr**

Figure 13. Shoreline behavior according to the change rate value and sign, (Luijendijk, 2018)

In the following pages relevant maps are included based on the spatial distribution of these categories.

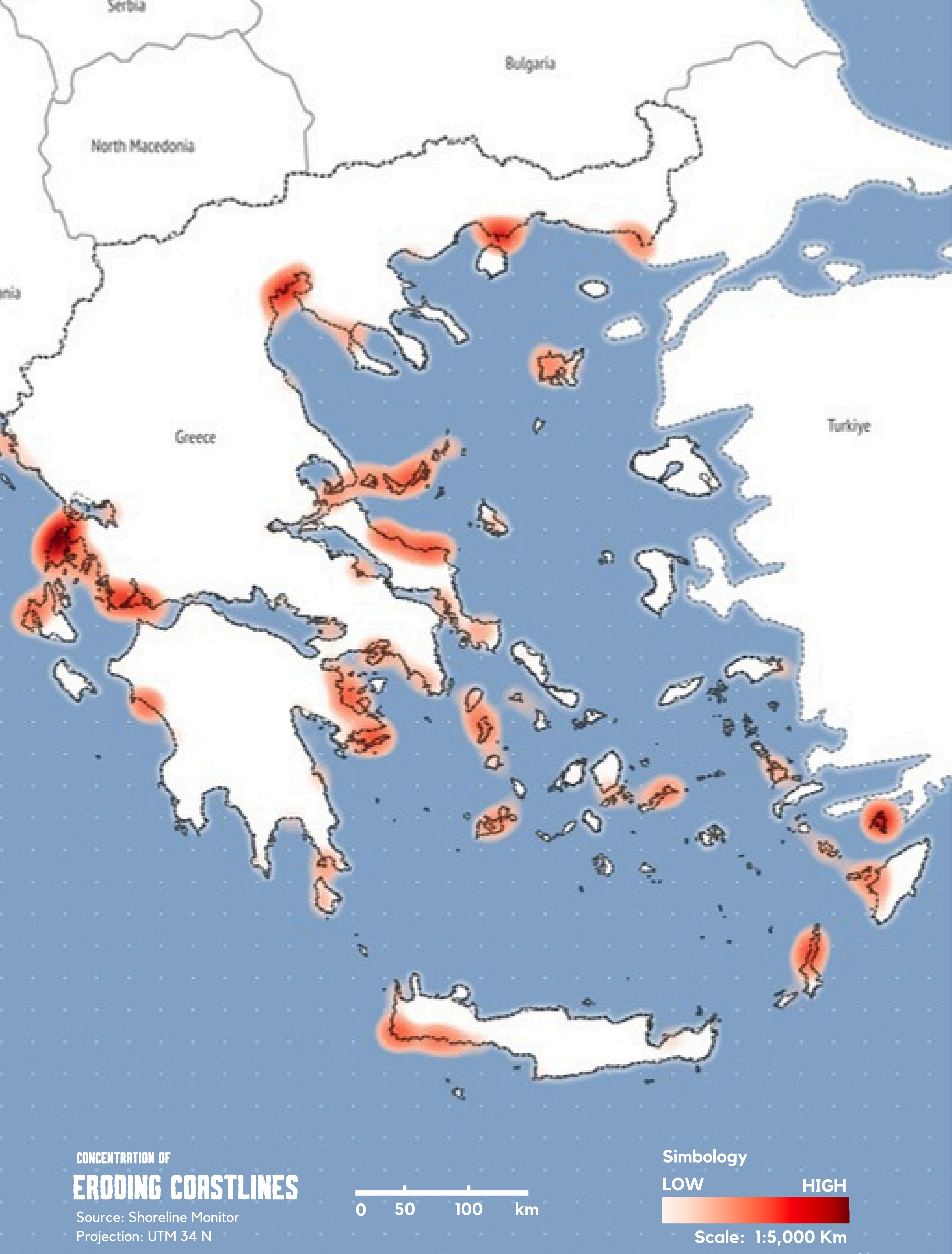


*Figure 14. Spatial distribution of **eroding** shorelines , (Luijendijk, 2018)*

Figure 15. Spatial distribution of stable shorelines, (Luijendijk, 2018)

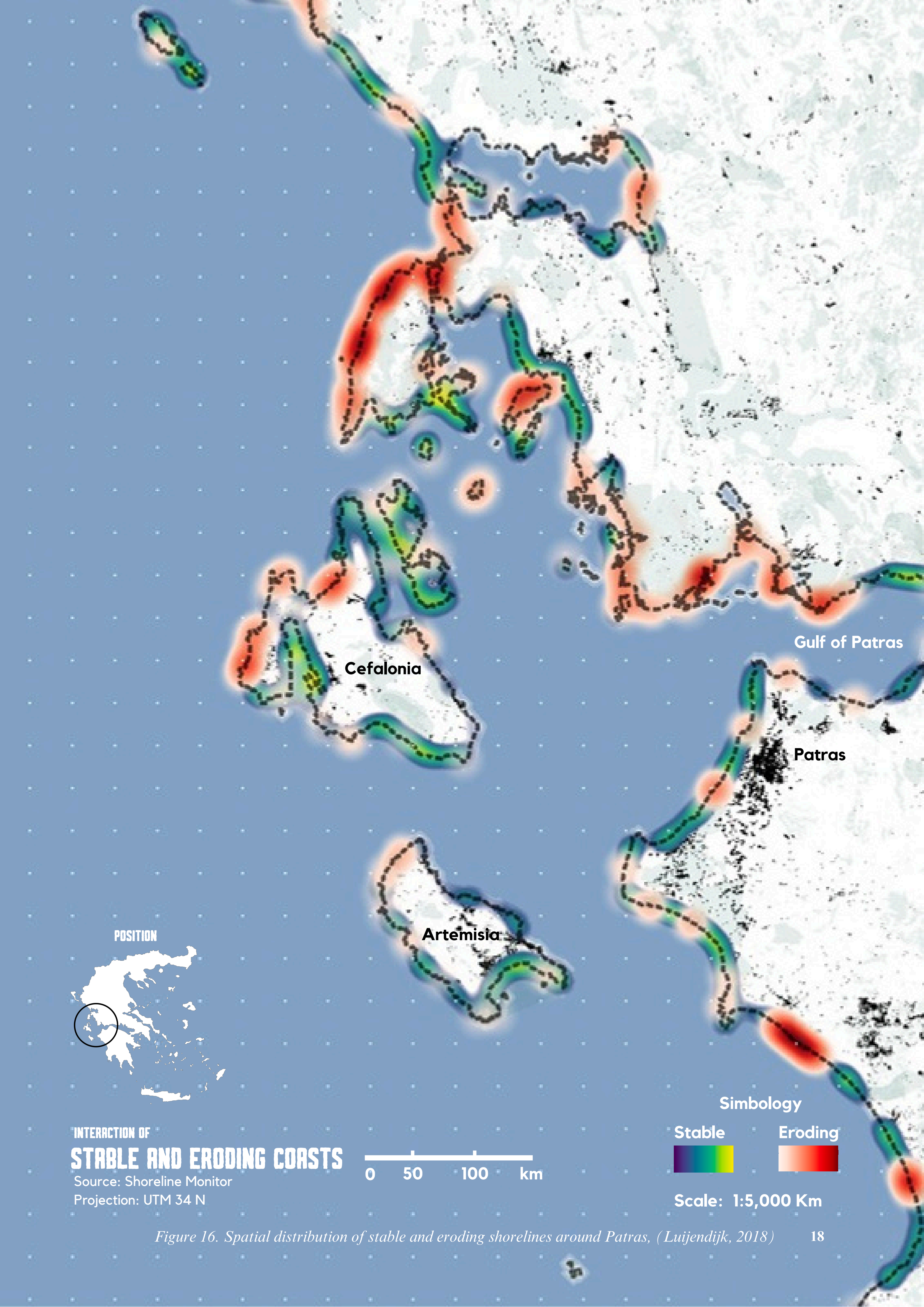


Figure 16. Spatial distribution of stable and eroding shorelines around Patras, (Luijendijk, 2018)

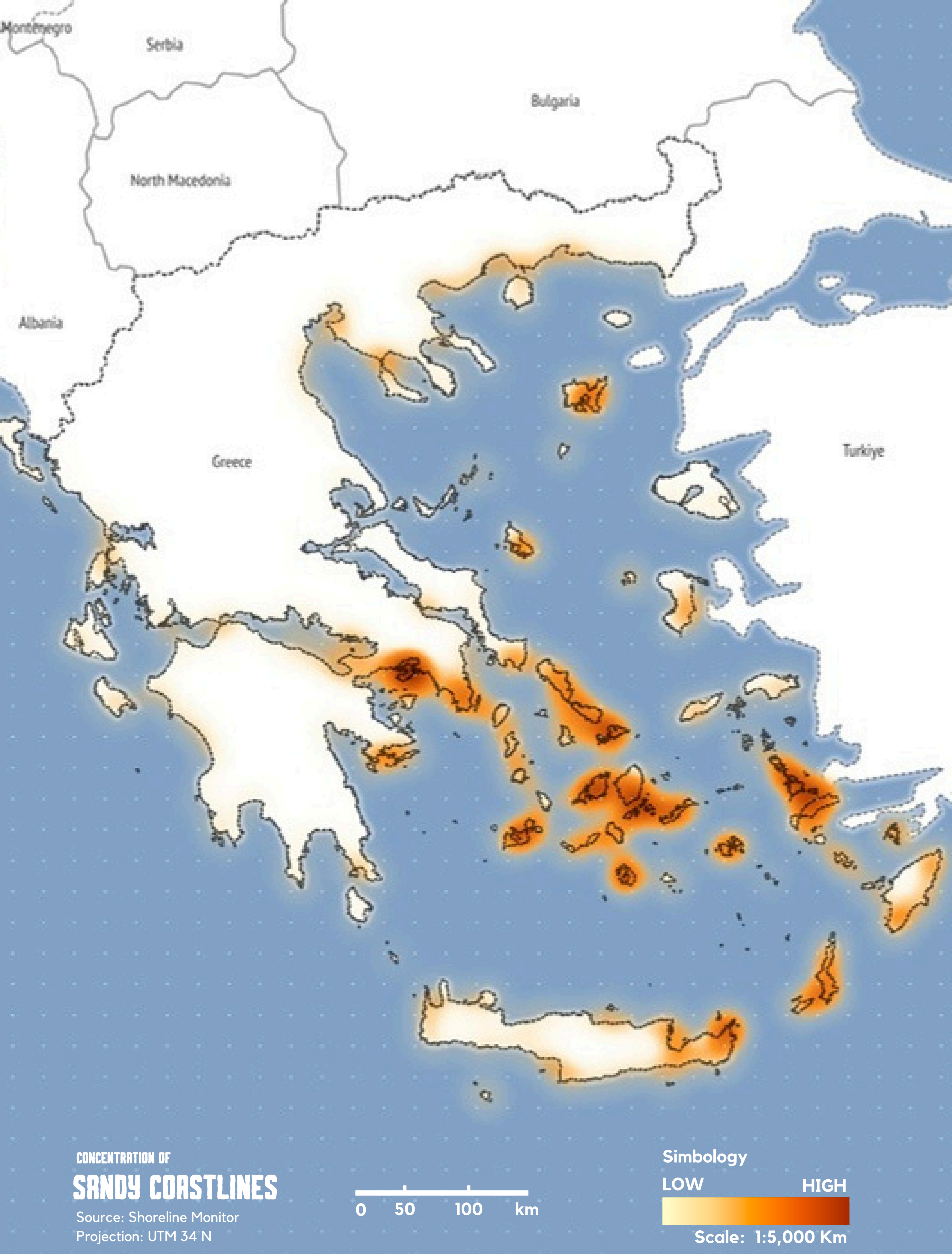


Figure 17. Distribution of sandy shorelines, (Luijendijk, 2018)

3.1.3 Exploratory data analysis

Before any processes were carried out on the databases, a statistical revision was performed, which included the following steps:

a) Filtering for sandy shorelines
b) Analyzing the data distribution
c) Removing values with ambiguity
d) Balancing the dataset
e) Creating homogeneous areas known as erosion hubs

These processes were conducted to improve the results, and the discussion section will further elaborate on this process, iterating through the database to understand how the limits defined in the *Table 0.2. Thresholds of coastal behavior* from Bird's book "Coastline Changes: A Global Review" were initially established.

Filtering for sandy shorelines

Shoreline Monitor is a project that investigates the state of beaches worldwide. The dataset distinguishes between sandy and non-sandy coastlines using machine learning algorithms. In the following diagram, these categories are analyzed with consideration of their future use in correlation calculations.

Figure 18: Examples of the categories within shoreline monitor , (Luijendijk, 2018)

Several inconsistencies were observed in the classification, and overall, the author believes this field exhibits **poor quality**. During the final stage of this thesis, new measurements from the non-sandy classification were included to test different data configurations and compare the results.

Conclusions from this process:

a) While the literature review points out that 30% of Greek sandy coastlines are classified as eroding, the analysis suggests they are relatively stable. The mean changerate for non-sandy beaches is **-0.267**, and for sandy beaches, it is **-0.115.** These results, indicate that both beach types experience **mild erosion** (Karkani et al, 2023)**.**

b) On the other hand, **non-Sandy** beaches have higher rates of RMSE, which points out to lower confidence levels on this classification.

c) Supporting this statement is also the fact that the uncertainty of the measurements on non-sandy environments have higher uncertainty levels, with a ratio of approximately 1.25, indicating that **non-sandy environments exhibit 25% higher uncertainty than sandy ones**

Filtering for RMSE

As explained in the section above, the main measurement in our dataset results from running a linear regression on the position of the yearly shoreline vectors from the satellite images to derive the number of meters per year that the boundary between water and land moves forward or backward. The authors of this dataset generated an RMSE value that quantifies how far, on average, the actual shoreline positions (SDS intersections) deviate from the positions predicted by the linear regression line.

The RMSE associated with the linear regression became a major concern for the author of this thesis when establishing a benchmark between seagrass environments and coastal erosion. As a result, a decision was made to remove higher RMSE values in the following way. This aspect will be reviewed in the discussion phase of this thesis, and a systematic inclusion of high RMSE values will be implemented.

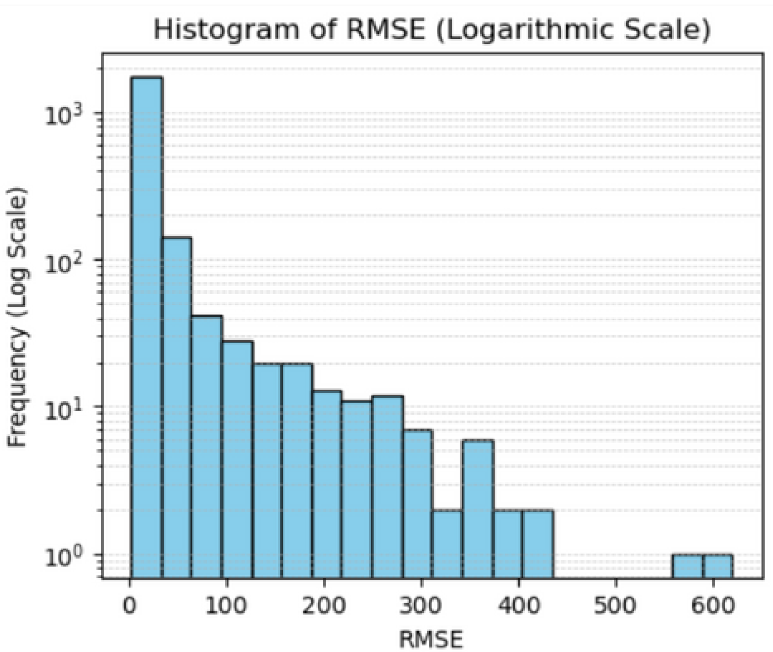


Figure 19. Histogram of RMSE values, (Luijendijk, 2018)

An initial analysis of the RMSE distribution indicated that the **mean RMSE is 27.32**, with a standard deviation of 52.11. This means that:

- On average, the predicted shoreline positions deviate by 27.32 meters per year from the observed positions, with a standard deviation of 52.11 meters per year. This variability suggests that some areas align more closely with the regression model, while others deviate significantly, potentially due to factors such as data quality, shoreline dynamics, or the complexity of local geomorphological processes.
- Additionally, to ensure that our calculations are grounded in reality, we will reference other papers with similar datasets.
- Specifically, the work of Vousdoukas et al., which draws measurements of coastal erosion using the same units, will be linked to our predictions for the same geographic area (Vousdoukas et al, 2020)

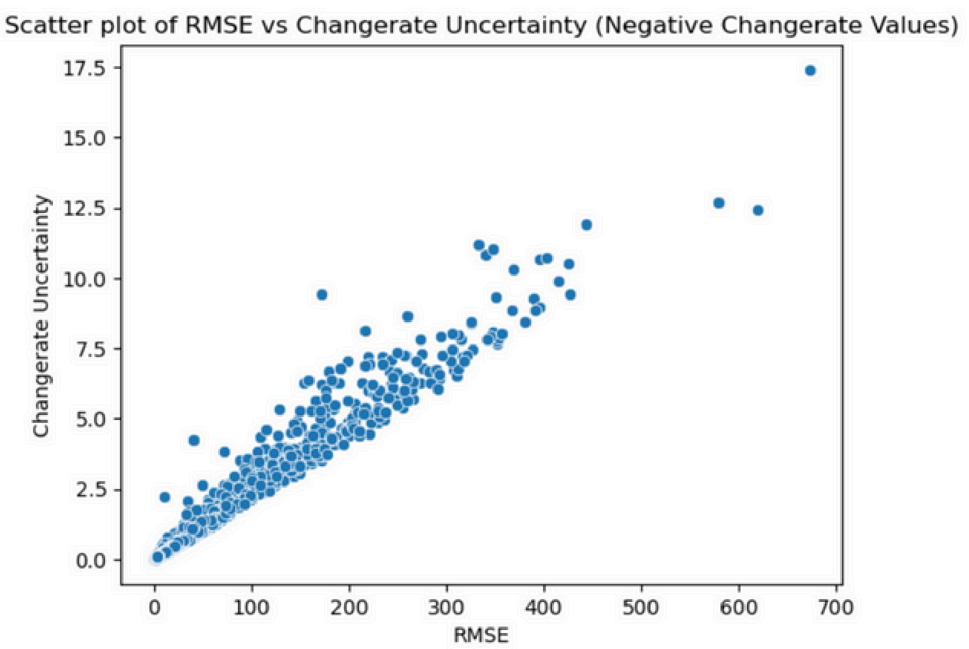


Figure 20. Scatter plot of RMSE and Change rate uncertainty values

- a) The first quality filter was defined by using the high RMSE and uncertainty values. As part of the dataset, the authors included a field called changerate_unc, which aligns perfectly with the distribution of RMSE, indicating that both fields are two sides of the same coin.
- After analyzing the quantile distribution of these parameters, a limit of 12.89 emerged as the threshold between poor and good quality values. This decision reduced our dataset to 10,911 measurements that exhibit good quality and do not present high levels of uncertainty.
- b) Below are the statistics of the new dataset: The overall mean of the values is -0.2961 meters/year, with a standard deviation of 0.31. When we compare this value to the projected erosion rate of 0.42 meters/year, as expressed by Vousdoukas for Greece's median, we can confidently assert that our database is reasonable and reliable.

- c) In the following graph, the distribution of data based on the categories established in Table 0.2: Thresholds of Coastal Behavior is analyzed:

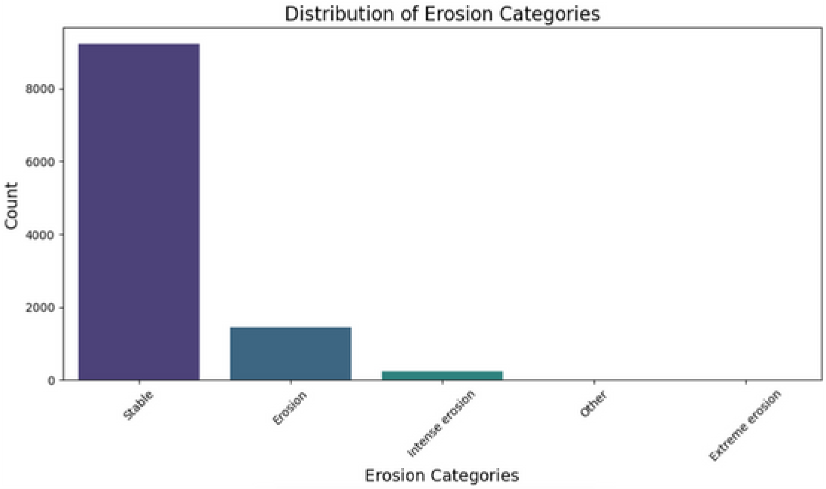


Figure 21. Values distribution based on Thresholds of Coastal Behavior

- a) As seen in the diagram above, we have an **unbalanced dataset** where the distribution of stable beaches accounts for nearly 84% of the data. To address this, we sampled values from this category and created a reduced database that accounted for the variance within this segment of the dataset.
- Additionally, a clustering procedure was performed using QGIS, creating 15 distinct areas.

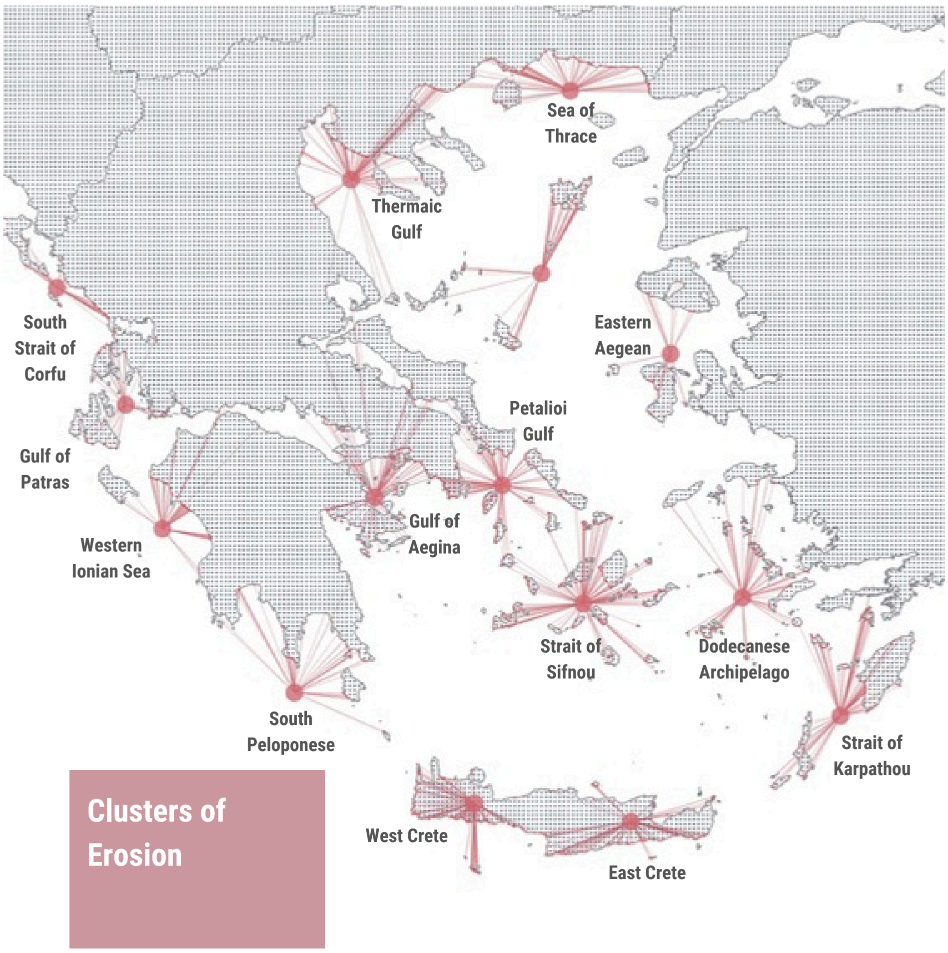


Figure 22. Clusters of erosion, (Topouzelis et al, 2018)

3.2 Seagrass dataset

The seagrass dataset was provided by the **Archipelagos Institute for Marine Conservation** as part of an internship agreement. It was developed by Konstantinos Topouzelis, the head of the Marine Remote Sensing group at the Department of Marine Sciences, University of the Aegean, Athens, Greece.

The dataset is part of the analysis documented in the paper *Seagrass Mapping in Greek Territorial Waters Using Landsat-8 Satellite Images*, published in 2018 (Topouzelis et al, 2018) . The analysis utilized images captured by Landsat during the summer seasons between 2013 and 2015, covering 13,676 km of Greek coastlines. These images were obtained by downloading and tiling 25-band composite images under three main conditions:
a) Cloud-free images
b) Calm seas (when possible)
c) Absence of major oceanographic phenomena (e.g., fronts, eddies)

The images were processed in four steps, including the filtering mentioned above. The second step involved atmospheric corrections, land masking, and cropping values beyond 40 meters depth. The critical part of the analysis focused on processing the red, green, blue, and NIR bands of the segmented images through an algorithm based on OBIA principles, using a software called eCognition Developer. This software groups spectral similarities and classifies these groups based on user-defined rules. With these conditions in place, the team was able to estimate accuracy based on each of the site codes in the Natura2000 dataset, which evaluates the presence of environments in Europe. The mean accuracy value in relation to the Natura2000 dataset was **76.29%.**

Additionally, fieldwork was conducted in the Aegean Sea to observe and measure the distribution of seagrass along the bathymetric profile in Samos, where the institute is located.

Figure 23. Eroding coastline in Samos, Greece.(Archipelagos Institute for Marine Research, 2024)

3.2.1 Fieldwork

During this field trip, surveys were conducted to observe the distribution, behavior, and overall height of the meadows along the first 50 meters of the shoreline through drone flights and kayak trips.

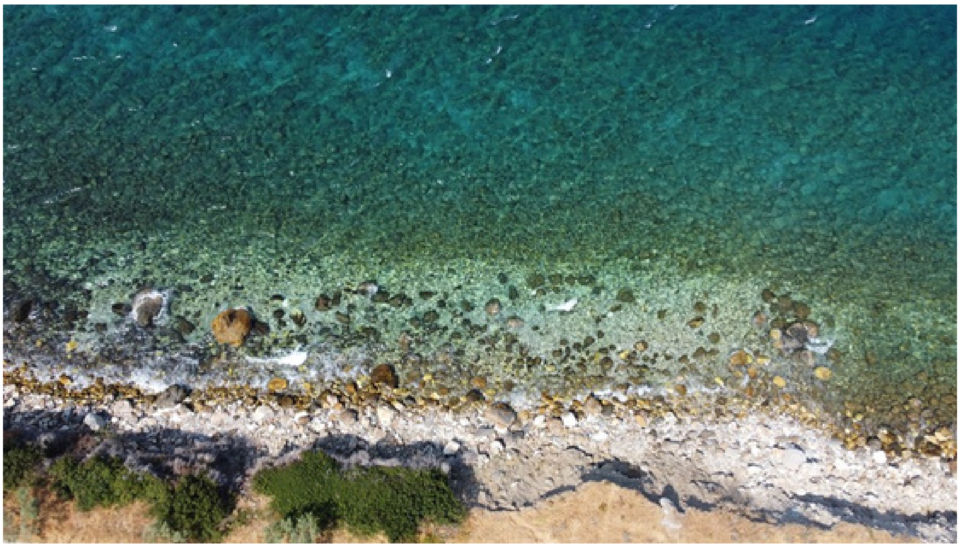


Figure 24. Drone survey with eroding shoreline, (Archipelagos Institute for Marine Research, 2024)

This first drone survey made evident the effect of coastal erosion on the region's infrastructure, where a nearby local road had become unusable due to an eroding slope. Additionally, the kayak surveys were used to dive and collect GoPro footage of the seagrass meadows.

Figure 25. Go pro surveys of seagrass meadows 50 meters into the sea and 25 meters below surface, (Archipelagos Institute for Marine Research, 2023)

The field trip component of this thesis became a valuable source of information on the nature of Posidonia oceanica, beyond its relation to this research, adding a deeper dimension to the importance of this environment. The key insight gained is that Posidonia oceanica meadows contribute to the richness of marine environments through wildlife nurseries. However, the legislation ensuring their preservation still has a long way to go in assessing their existence, ecological role, and future conservation needs.

Figure 26. Distribution of seagrass meadows in Europe, North Africa and Asia , (EMODnet, 2020)

Figure 27. Distribution of seagrass meadows in Greece, (Topouzelis et al, 2018)

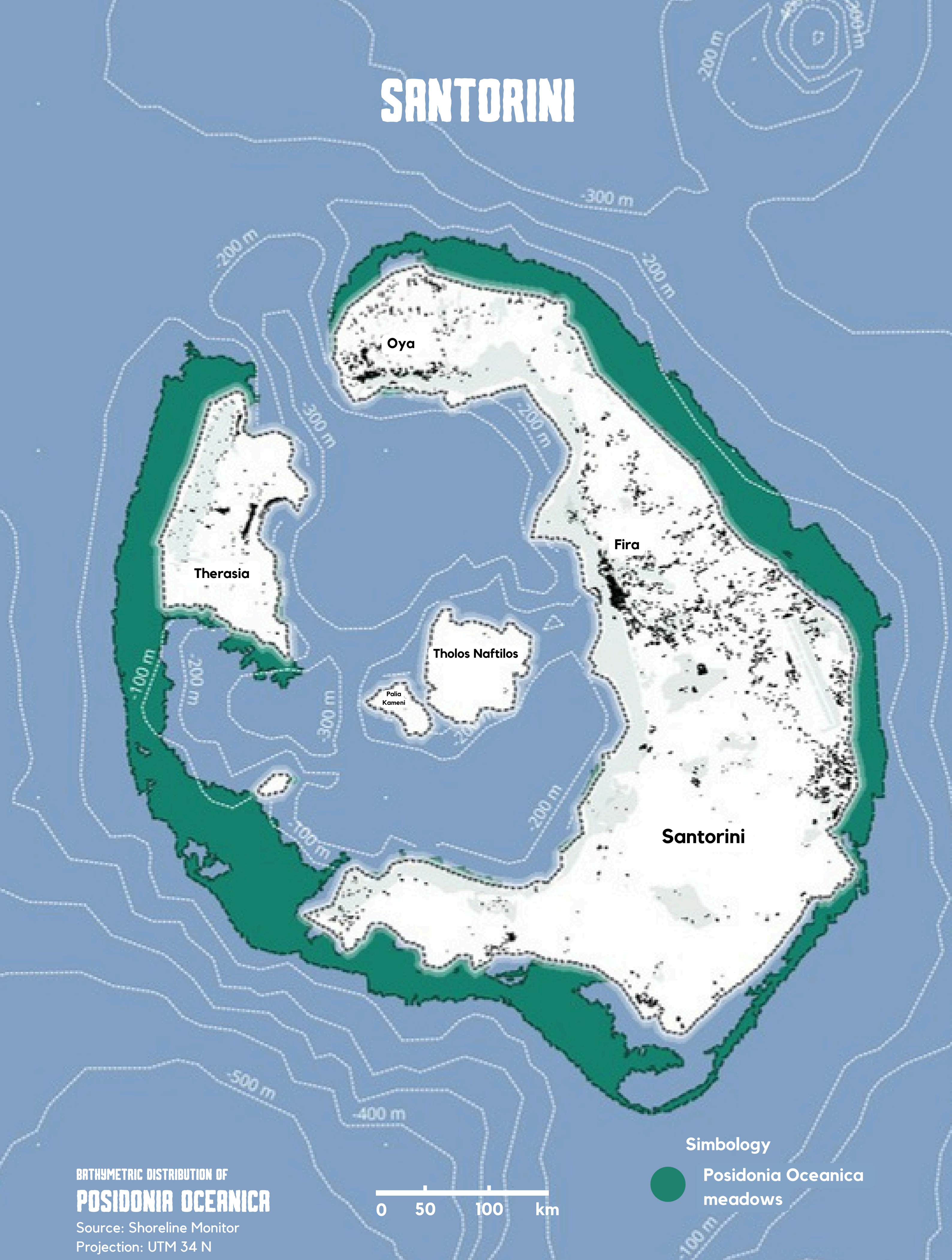


Figure 28. Distribution of seagrass across the bathymetric profile, (Topouzelis et al, 2018)

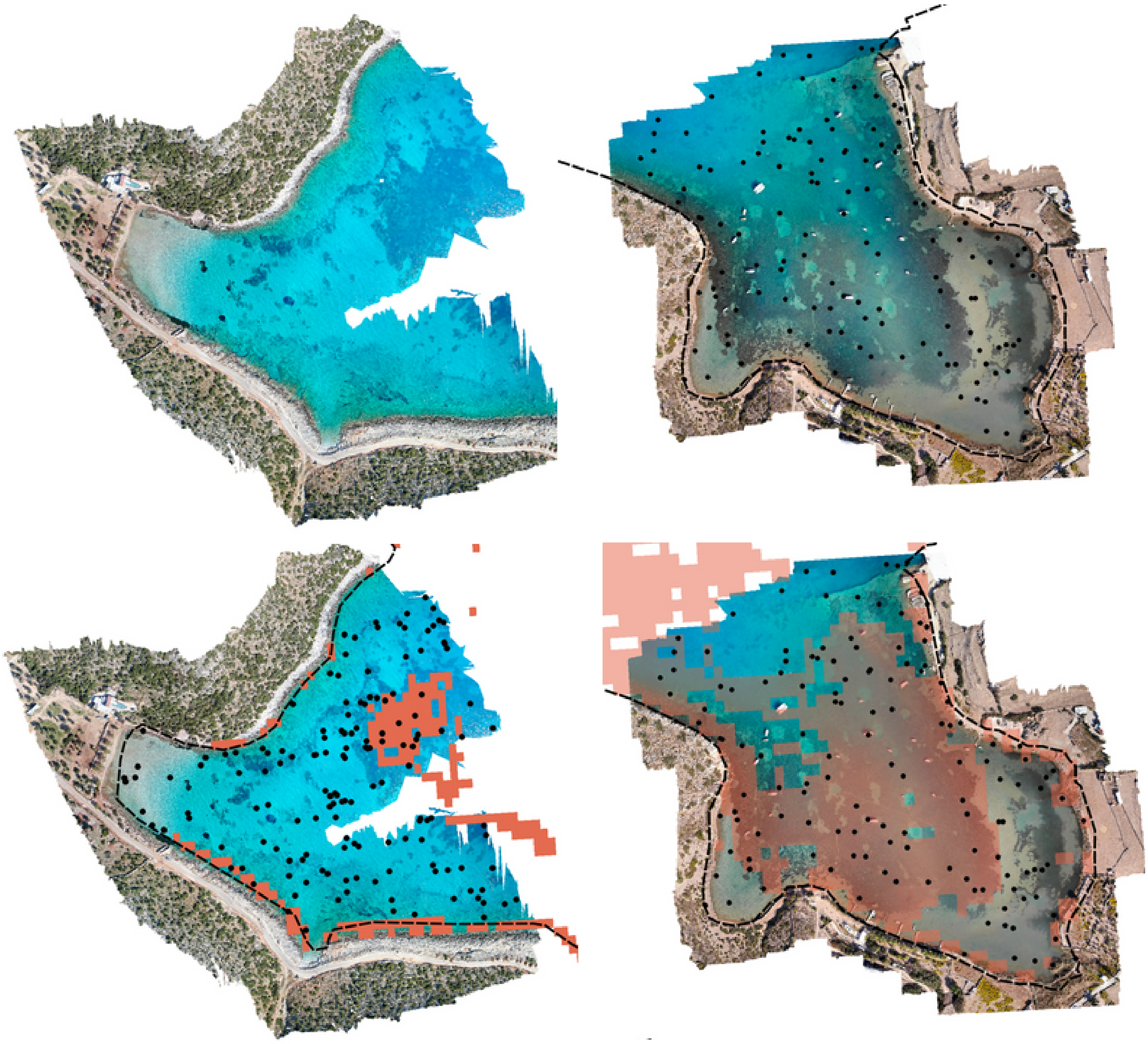
3.2.3 Accuracy assessment

Additionally, an accuracy assessment was conducted to evaluate the quality of the data. A trip was planned to the island of Lipsi, where seagrass meadows are easily accessible and consistent wind conditions allow for the use of drones.

The bays of Piatis Gialos and Lipsi were selected, covering an area of approximately 0.35 km², where 150 points were overlaid on the seagrass features. Overall, the algorithm used by the authors of the paper resulted in the following accuracies and precisions:

Platis Gialos, Lipsi
Accuracy: 47%
Precision: 84%

Lipsi Bay
Accuracy: 65%
Precision: 85%



Simbology:

● Accuracy assesment points   Seagrass meadows obtained trough Sentinel-2

Figure 29. Accuracy assessment of the seagrass dataset ,
(Archipelagos Institute for Marine Conservation, 2023)

By conducting fieldwork and consulting with specialists at the institute, the size of seagrass meadows that can effectively impact the preservation of coastal dynamics was defined for the study. In the following diagram, different configurations of meadows and their relation to the shoreline are illustrated.

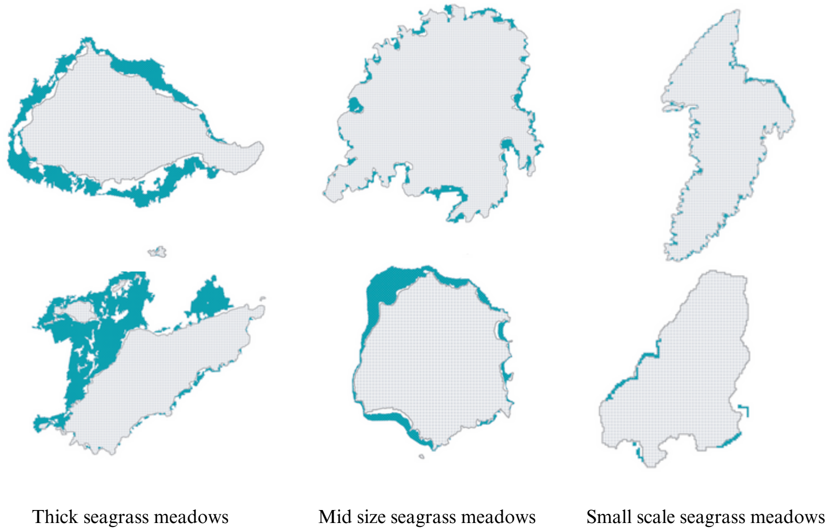


Figure 30. Typologies of seagrass meadows, (Topouzelis et al, 2018)

A process to remove polygons that are too small to represent any potential protection against coastal erosion was carried out, using a threshold of 15,000 m². This limit was based on observations made during the field trip and interviews with researchers at the Archipelagos Institute for Marine Conservation.

Figure 31. Seagrass meadows based on clusters of erosion, (Topouzelis et al, 2018)

3.3 Transect analysis

Two approaches were implemented to geospatially account for the relationship between seagrass meadows and coastal dynamics:

a) Presence and absence (categorical attributes)
b) Overlapping area (continuous attributes)

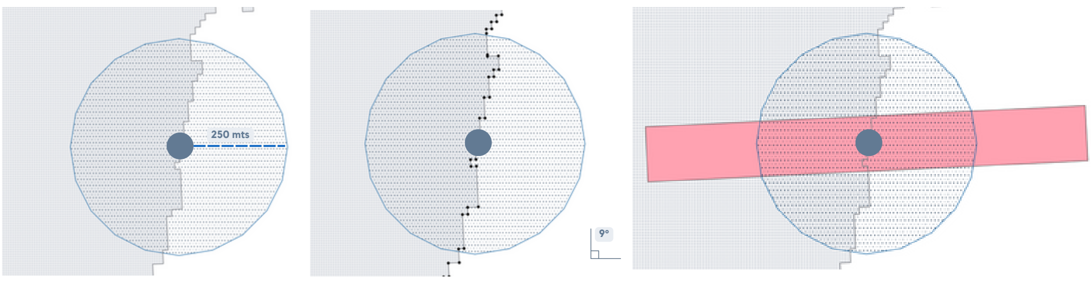
These methods were chosen because they allowed observation of the influence in two forms: one that considers only the existence of seagrass environments, and the second that measures the area contributing to the study versus the area lost throughout the entire analysis. The goal was that the first approach would prove the relationship, while the second would indicate the degree of that relationship.

In their analysis, *Hagenaars et al.* highlighted the use of transect lines as the best solution for studying coastal dynamics, due to their ability to capture the state of the shoreline at different times simultaneously. This same approach was implemented in this analysis to compute the presence of seagrass and erosion at both time points, using the same unit of measurement: **m².**

To create the transect polygon, we first obtained an average measurement of the shoreline angle at the closest point measurements, then created a line orthogonal to this angle. The process was as follows:

a) Buffering the point measurement by 500 meters
b) Clipping the shorelines within the 500-meter buffer
c) Obtaining the vertex of each line, which generates an attribute for the angle of the line connecting each point
d) Averaging the angle values
e) Using the tool "Rectangles, Ovals, and Diamonds" to create a transect ranging from 250 to 2000 meters, using the angle in the attribute table and the point as the origin of the transect.

This process successfully generated a dataset of transect lines onto which the presence of seagrass and its covering area were projected, one for each measurement.



a) Buffering the coordinate a) Vertex definition c) Transect tracing based on angle definition

Figure 32 . Transect tracing for every measurement in Shoreline Monitor dataset, (Hagenaars, 2018)

After each of the transect polygons was traced, two processes were applied to each polygon:

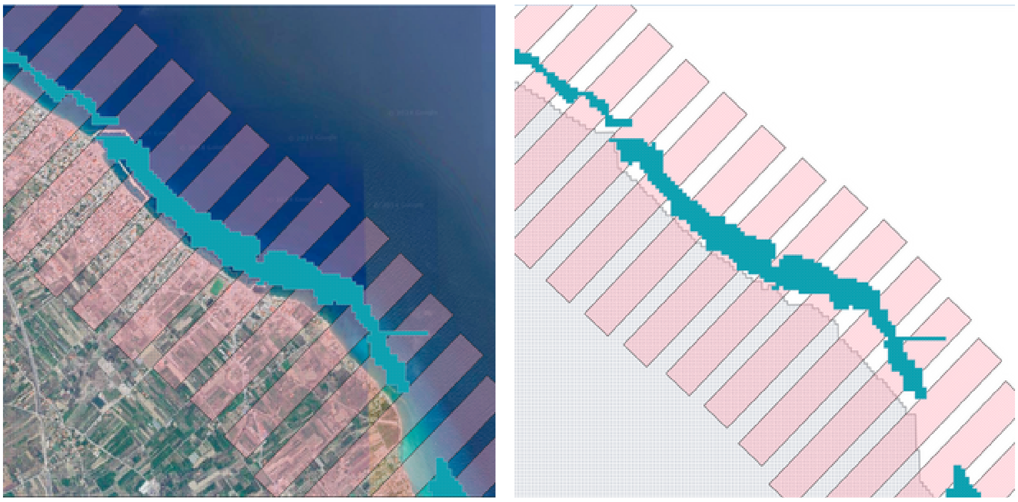


Figure 33. Set of transects overlapping with seagrass meadows, (Hagenaars, 2018)

The first process applied to the dataset was a spatial overlay to define the presence of seagrass beneath the transect. Four possibilities emerged from the overlay of the transect and seagrass meadows:

a) The transect **shows erosion** in the change rate attribute (< -0.5 m/yr) and overlays a seagrass meadow larger than 15,000 m².
b) The transect **does not show** considerable erosion in the change rate attribute (> -0.5 m/yr) and overlays a seagrass meadow larger than 15,000 m².
c) The transect **shows erosion** in the change rate attribute (< -0.5 m/yr) and does not overlay a seagrass meadow larger than 15,000 m².
d) The transect **does not show** considerable erosion in the change rate attribute (> -0.5 m/yr) and does not overlay a seagrass meadow larger than 15,000 m².

The result of this matrix is plotted in the following diagram, where we can observe the distribution of values across the four options described:

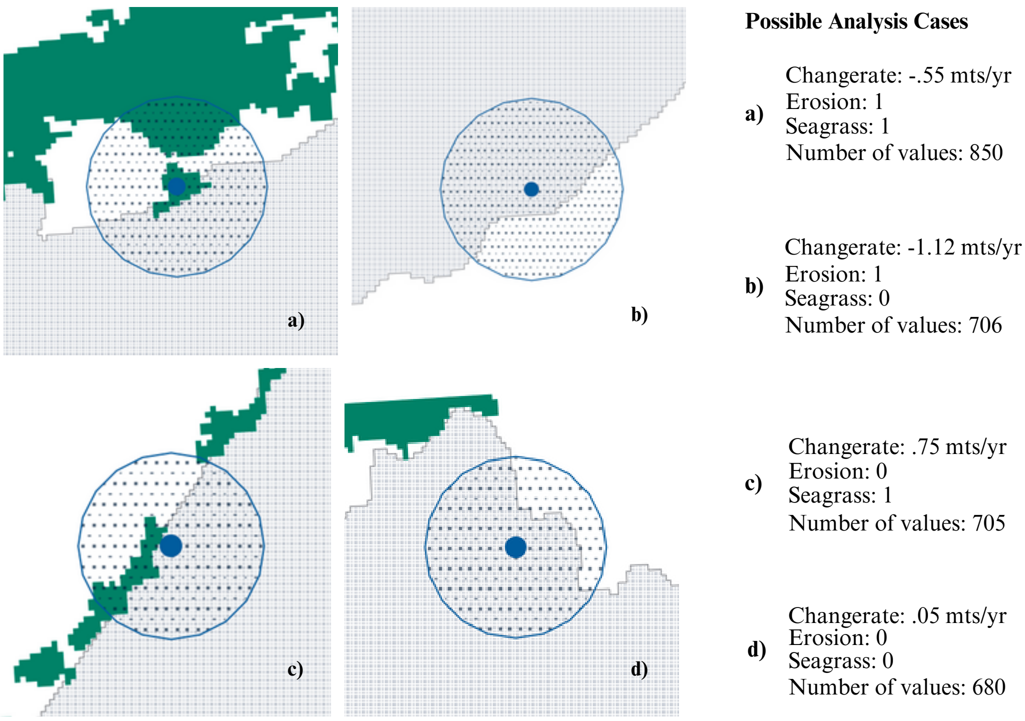


Figure 34. Configurations of possible cases of interaction, (Hagenaars, 2018)

Approach b: Relating the areas of influence

How to obtain the total area of erosion?

A second approach was implemented to determine whether areas of erosion are related to areas of seagrass.

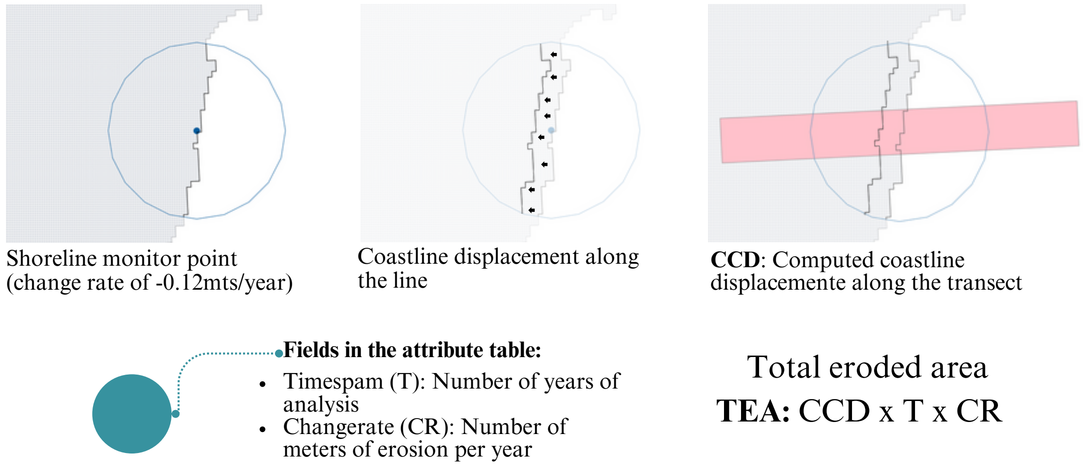


Figure 35. Representation of how the erosion area was computed., (Hagenaars, 2018)

As our measurement for coastal erosion is expressed in meters per year, we multiplied this attribute by the number of years of analysis obtained from the "Timespan" attribute. This attribute represents the number of years of data available for each transect. By doing so, we obtained the total number of meters eroded for each measurement.

Once we had the one-dimensional measurement of total erosion, we projected the length into the transect width of 250 meters. This step transformed the point-based measurement into a surface area that could be compared to the seagrass area using linear regression. This process was primarily carried out using QGIS.

The second part of this section involved designing a Python script to:
a) Iterate through the list of transects.
b) Overlay the transects with the seagrass meadows.
c) Clip the seagrass shapefile.
d) Compute the area of overlap with the transect.
e) Iterate through the next transect line.

This process is exemplified in the following diagram:

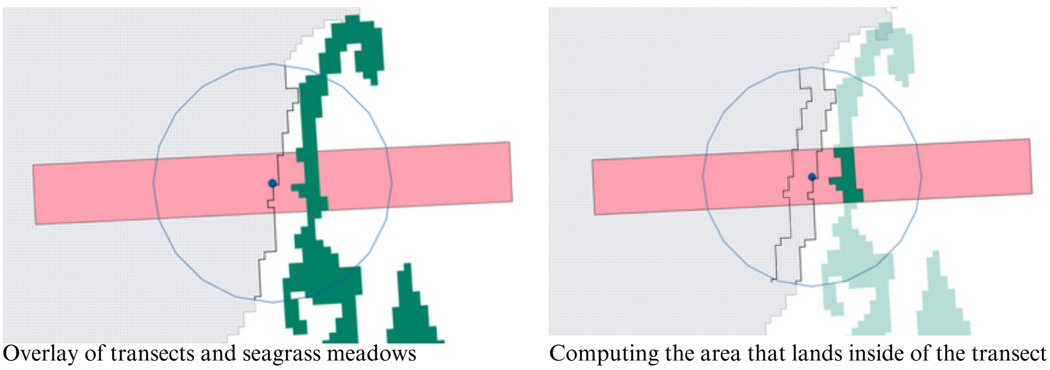


Figure 36. Overlay of area on the transect polygon, (Hagenaars, 2018)

After this procedure was executed, we had both the area of overlap for erosion and the seagrass cover within the same polygon.

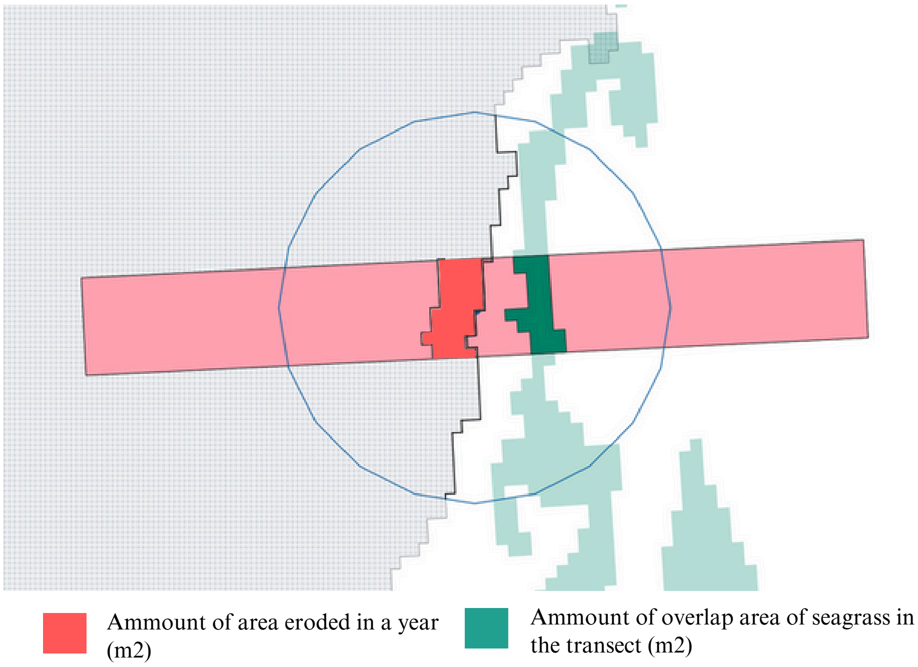


Figure 37. Overlay of seagrass and erosion area on the transect polygon, (Hagenaars, 2018)

In contrast to the results obtained from the first linear regression, this process failed to demonstrate any relationship between seagrass areas and erosion areas, as it explained none of the variance of the dependent variable.

R-squared (0.0003): The model explains **none of the variation in the dependent variable**. The results from this regression indicate that, in the absence of seagrass, the expected value of erosion is 4,479 m² in total, corresponding to a rate of 0.55 m/year over the **32-year analysis period.** This value aligns with average erosion rates, suggesting that seagrass does not significantly impact erosion.

Overall, these results failed to demonstrate that coastal erosion is mitigated by seagrass environments. However, during the discussion phase of this thesis, a different approach to erosion rates was employed to achieve two objectives:
a) Demonstrate that, in a small proportion of cases, high rates of coastal erosion can be mitigated by healthy seagrass meadows.
b) Show that seagrass plays a significant role only until coastal dynamics reach extreme levels.

Underwater survey
Agios Konstantinos, Samos
Greece, 2024

Figure 38. Underwater environment
(Archipelagos Institute for Marine Conservation, 2023)

4.1 Results

After computing the presence and absence of seagrass and erosion, we ran a model to estimate the probability of erosion occurring as a function of seagrass presence using logistic regression. In this case, the Maximum Likelihood Estimation (MLE) was used, with erosion as the dependent variable.

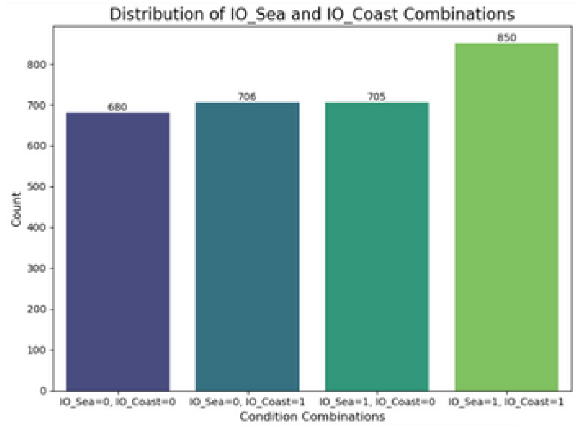


Figure 39. Distribution of erosion categories

Modeling the probability of erosion occurring as a function of seagrass presence using logistic regression. The results are as follows:

Table 3. Table of results from the presence approach regression

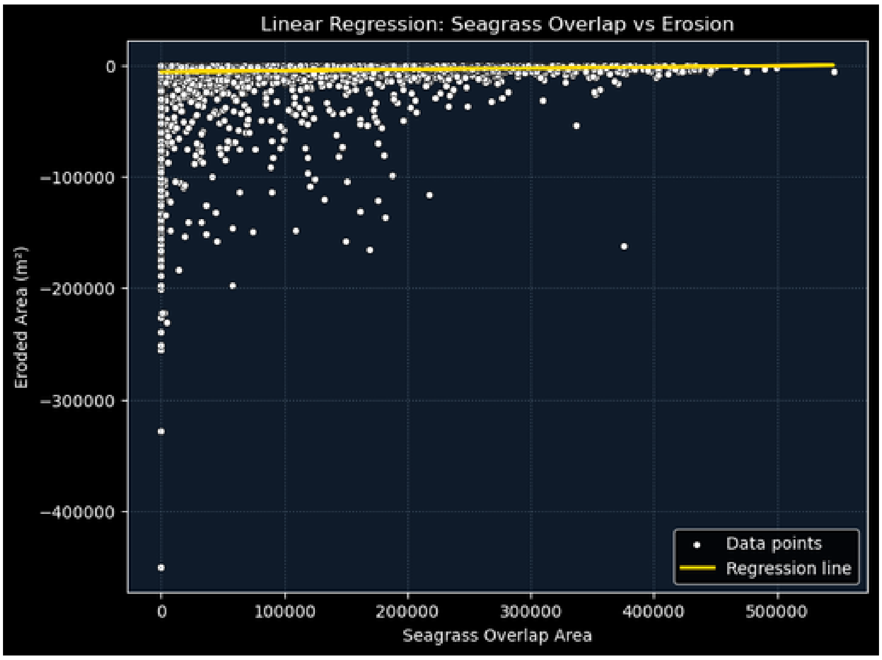
Method: Maximum Likelihood Estimation (MLE).	
Log-Likelihood: -2158.7 LL-Null: -2230.8	The Log-Likelihood (LL) function compares a null model, which assumes no relationship, to a model that accounts for the impact of a variable on a certain outcome.
Difference of values: −2230.8−(−2158.7)=−72.1	Higher log-likelihood (closer to 0) indicates better model fit. This indicates an improvement in the model after adding the predictor (seagrass presence), but it ultimately explains little of the complexity of the phenomenon, highlighting the need to consider other factors.
R-squared: 3.23%	The proportion of variability in the dependent variable explained by the model.
Coefficients Intercept $e^{0.4562}$=1.57 β0=0.4562	It represents the log-odds of erosion when seagrass is absent. Without seagrass, the odds of erosion are 1.578:1, corresponding to a ~57.8% likelihood.
Seagrass coefficient (β_1 = -0.8741):	When seagrass goes from 0 to 1, the log-odds of erosion decrease by 0.8741.
Standard errors 0.057 for Intercept 0.074 for Seagrass	They represent the precision of the coefficient estimates. Smaller standard errors indicate more precise coefficient estimates.
p-values 0.0042 for Intercept 0.0033 for Seagrass	These p-values suggest that both variables are significant predictors of erosion.

Results of the initial regression indicate that the presence of seagrass does not mitigate coastal erosion in a considerable way. In the paper: *Evaluation of seagrass as a nature-based solution for coastal protection in the German Wadden Sea*, the methodology reflects that seagrass environments mostly have effect on the damping coefficient of wave dynamics, showing that even tough there's a link between both it's not a direct relation that can be expressed in numerical numbers trough the regression, indicating that there's not a way to mathematically model the influence of seagrass meadows on the changerates available (Jacob et al, 2023).

Reinforcing this insight is the fact that the regression using the area eroded versus the area of seagrass overlap shows similar results. Out of the 24,431 measurements of the database 59% of them presented negative change rates, these points were compared trough a linear regression with eroded area as the dependant variable and seagrass area as its independent variable. The regression showed a very low R-squared value (0.0036), indicating that seagrass area explains only a tiny fraction of the variability in eroded area. The adjusted R-squared (0.0035) reinforces this weak relationship. While the F-statistic (51.99) and its extremely low p-value (<0.0001) suggest statistical significance, the overall explanatory power of the model remains minimal. This suggests that other factors beyond seagrass area are driving the observed erosion patterns.

In order to assess objective number three, a process of further cleansing the database was implemented to optimize the results and define what are scientists talking about when they say the role of seagrass is nuanced:

By removing the records of coastlines that presented **stable conditions** (erosion values between 0 and -0.5 mts/year) the regression showed a slight improvement, with the R-squared increasing to 0.0127. This remains a very low value, indicating that seagrass area still explains only a small portion of erosion variability.



Intercept: -6074.7124 **R-squared: 0.0035615584** **F-statistic: 51.991599**
Coefficient: 0.011053 **Adjusted R-squared: 0.00349305** **p-value (F-statistic): 5.848e-13**

Figure 40. Linear regression of coastal erosion vs. change rate

By computing the **slope of the areas where seagrass meadows are located** and analyzing its relationship with coastal erosion, the regression analysis showed a weak and statistically insignificant association between these variables ($R^2 = 0.0019$, Adjusted $R^2 = 0.0013$, F-statistic = 3.37, $p = 0.066$). This indicates that the slope does not provide additional explanatory power in understanding the numerical relationship between seagrass meadows and erosion rates. Consequently, the role of slope in influencing coastal erosion in seagrass-covered areas appears to be minimal or negligible within the analyzed dataset.

When compared to the dataset containing only **records of sandy beaches,** the linear regression showed no sign of improvement or new insights into the relationship between seagrass and coastal erosion dynamics ($R^2 = 0.0028$, Adjusted $R^2 = 0.0027$, F-statistic = 21.95, $p < 0.00001$). This result disproves the belief that a specific type of coastline would significantly alter the characteristics of shoreline change in the presence of seagrass. Instead, the findings suggest that seagrass-erosion interactions remain consistent across different coastal environments, reinforcing the idea that other factors—such as hydrodynamics, sediment transport, or seagrass density—may play a more influential role in shaping shoreline behavior.

When the **size of the meadow** was considered by removing small polygons from the dataset, no significant changes were observed in the regression results ($R^2 = 0.0023$, Adjusted $R^2 = 0.0018$, F-statistic = 4.93, $p = 0.026$). This suggests that meadow size alone does not play a decisive role in influencing coastal erosion dynamics. Instead, it is likely that the density of the seagrass within the meadow, rather than its overall spatial extent, has a more substantial impact on shoreline stability. The findings highlight the need to consider structural characteristics such as shoot density and biomass distribution when assessing the protective role of seagrass in coastal environments.

The following table condense what was processed in these calculations, making evident that the main indicator that reduce uncertainty of the role of seagrass meadows in coastal erosion is the degree of erosion that is experienced in the position of the transect which indicates that Seagrass meadows become relevant when coastal erosion is in its late and critical stages above -0.5 meters per year.

Table 4. Parameters that influence the nuanced role of seagrass in coastal erosion

Scenario	# Records	R2	P value	Specifications
Regression based on presence	14,548	3.23%	.0033	< 0 mts of erosion per year
General regression	14,548	0.36%	<0.0001	< 0 mts of erosion per year
Distance to seagrass meadow	3,203	0.17%	<0.0001	Closest distance to meadow
Slope between the shoreline and seagrass meadow	1,803	0.13%	0.066	Shorelines with < -2% slope
Size of the seagrass meadow	2,129	0.23%	0.026	Meadows above 5000 m2
Unstable coastlines	2,284	1.27%	<0.0001	< -0.5 mts of erosion per year
Sandy coastlines	2,074	0.28%	< 0.00001	Based on attribute Sandy/Rocky

4.2 Discussion

Linear Regression Analysis Highlights

Effect of Seagrass Area on Erosion:

- The regression analysis revealed a small and statistically insignificant effect of seagrass area on erosion. The coefficient for overlap suggests that for every 1 m^2 increase in seagrass area, erosion decreases by a negligible **0.0278 m^2**. This implies that other factors play a more significant role in contributing to erosion dynamics.
- **Model Fit** : The model's R2 value of 0.0003 indicates that the seagrass overlap area **explains virtually none of the variability in erosion.** This highlights the weak relationship between the two variables in the current dataset and underscores the complexity of coastal erosion processes.
- P-Value: The p-value for the overlap area was 0.503, well above the commonly used significance threshold of 0.05. This indicates that the observed effect **is likely due to random chance**, providing insufficient evidence to conclude a statistically significant relationship between seagrass presence and erosion reduction.

If the methodology does not prove that coastal erosion is prevented by seagrass, are there specific categories or cases of coastal erosion that are, in fact, influenced by the presence of seagrass meadows?

In the study published by *Infantes et al*, the researchers highlighted the nuances involved in studying erosion through the lens of seagrass. The study captures the complexity of this issue:

> *Although cliff erosion is widely regarded as an important driver of coastal dynamics, the role of vegetation roots in mitigating this process remains unclear (Infantes et al., 2022).*

As the study emphasizes, coastal erosion is an intricate phenomenon influenced by numerous interrelated factors. Interestingly, when the same linear regression was applied specifically to the zones with the highest erosion rates, the results aligned more closely with our expectations

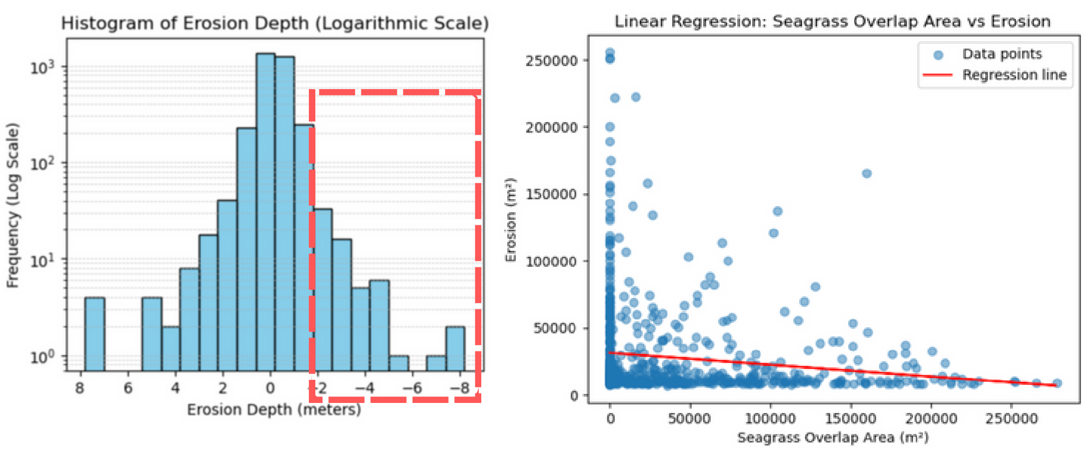


Figure 41. Performance of the linear regression model in the highest ranges of coastal erosion.

Insights gather from this exercise:

a) **Sign Change in the Linear Regression Equation:** In the initial approach, the relationship was positive, which contradicted expectations since a negative relationship was anticipated based on the literature. In the second round, the trend line's sign changed from positive to negative, aligning with our expectations when we stated at the beginning of this work that **"the presence of seagrass meadows actively works against coastal erosion.**

b) Explanatory Ability of the R^2 Parameter: The R^2 value indicated that, even on a small scale, **seagrass meadows influence coastal dynamics,** but **only when coastal erosion rates are high**. The R^2 value suggests that seagrass explains only 2% of the variance in the dependent variable.

c) Third Insight from the Analysis: A third key takeaway from this process is that the results from the first approach should be discarded as unimportant. Instead, **the analysis should focus on high erosion rate areas**, where a significant correlation may be found.

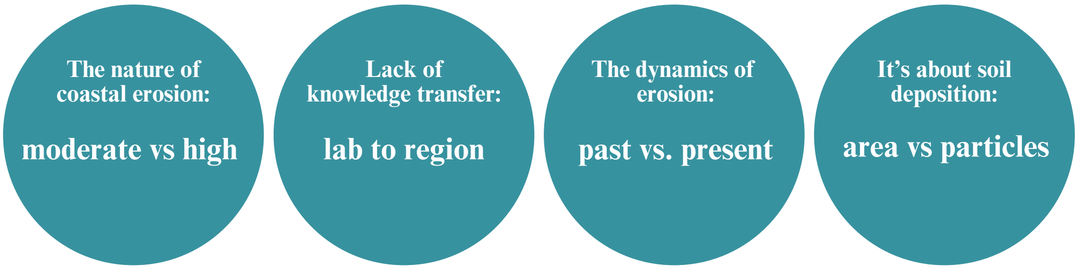


Figure 42. Challenges in the implementation of vegetation as coastal stabilization mechanisms

When do moderate become critical?

- The most relevant insight is that, at a certain point, the effect of seagrass meadows starts to become evident, while it remains mild or insignificant throughout the range of moderate erosion.
- *What happens during the critical stages of erosion that causes the meadows to appear in the regression?* This question may suggest a variance in the phenomenon or a shift in the nature of the physical processes involved. We will return to this point after discussing the other insights gathered in the research

How do we transfer knowledge to regional studies?

- There is a general lack of knowledge transfer from high-accuracy modeling conducted in laboratory environments to large-scale or regional analyses. A clear approach to scaling up the knowledge generated by models such as the SPH technique or Lagrangian methods in laboratory settings has not been effectively translated to regional scales. When attempting to integrate multiple dimensions into a cohesive analysis, a knowledge gap becomes evident.
- The average spatial resolution of oceanic parameter databases is too coarse to adequately address the spatial resolution required to study coastal erosion. For instance, the average spatial resolution of raster data from NOAA is approximately **4.6 km (1/24° x 1/24°)**, which is insufficient for high-accuracy methodologies.

How do we record the evolution of the problem?

- A third insight is that the nature of coastal erosion is constantly evolving. As we develop more advanced (or automated) methods to monitor shoreline positions through satellite imagery, drones, and algorithmic segmentation, **the definition of coastal erosion also continues to evolve.**
- The reference studies used during the literature review revealed a shifting trend in how mild or severe erosion scenarios are interpreted by each generation of coastal engineers. Through human influence, coastal dynamic behaviors are being altered and accelerated, creating new challenges and prompting a reassessment of the established references built over the decades.
- For example, in the analysis conducted by Tiffany R. Anderson et al., the research team found that valid studies of shoreline dynamics under a steady rate of erosion are likely underestimating the problem for present and future scenarios. The model, which used Hawai‘s as a case study, projected that coastal erosion on Hawai‘i’s beaches could double by mid-century.

> *“When we modeled future shoreline change with the increased rates of sea level rise (SLR) projected under the IPCC’s ‘business as usual’ scenario, we found that increased SLR causes an average 16 to 20 feet of additional shoreline retreat by 2050, and an average of nearly 60 feet of additional retreat by 2100,”*
>
> *(Anderson et al, 2015)*

- In the 1980s, when the first coastal erosion studies were conducted by the U.S. Army Corps of Engineers and the report on the eroding coasts of Florida was published, their definition of stable shorelines was broader than what is considered stable today. In the current context, where Greek sandy coastlines are experiencing erosion rates of 0.3 to 0.5 meters per year, a 50-year-old definition based on entirely different conditions and degrees of erosion cannot be applied as the standard for measuring current conditions (Woodhouse, 1974).

What’s the role of seagrass in coastal erosion?

- After revisiting the literature to identify potential sources of error in the methodology and to explore analogous examples from other regions around the world, the work of two engineers from the U.S. Army Corps of Engineers, who implemented a similar approach at the regional scale in North Carolina, presented their results as follows:

> *Stabilization was a major objective of the study, but one for which we were unable to develop satisfactory evaluation procedures. The problem is the lack of unaffected or unbiased controls.*
>
> *(Woodhouse, 1974)*

- An important nuance mentioned by the team is that vegetation affects the dynamics that enable particle deposition, rather than directly decreasing wave energy. As shown in this image from a field trip of the underwater profile, the area influenced by particle deposition is quite narrow. In this sense, seagrass meadows primarily affect the material balance in the shallow bathymetric zones, not the main driver of erosion—wave energy.

5. Conclusions

After running the procedures the results don’t show a clear causality between the prescence of seagrass and mitigating coastal erosion. In that case, can this analysis be used as a stepping stone to delimitate what the scientific community has label as the “nuanced role of seagrass to mitigate coastal erosion”. During the second part of the analysis this question was explored and the following insights were obtained:

- The highest rates of erosion tend to be the most prominent detail of the significant role of seagrass to mitigate erosion, considering that the explanation power of the independent variable at normal rates are amplified by a factor of three when are compared against rates that go above >1 meter per year.
- The distance of the seagrass polygon to the transect plays a similar role in explanatory power of the independent variable, making evident that when healthy and large scale meadows are in front of an eroding coastline the power of nature based systems become more relevant.
- The third and last insight out of this section reveals that sandy environments are more adept to fullfil the conditions under which seagrass can work efectively to reduce wave intensity and act as a mitigator erosion in the greek coastlines. Under these conditions posidonia oceanica can effectively help stabilize the sediments floating.
- After conducting this research, it’s clear why most studies on coastal erosion at the medium scale and in controlled lab environments tend to perform the best. The variation and lack of homogeneity within regional scales make it impossible to accurately assess the role of vegetation in coastal dynamics. The approach taken in this thesis lacked the ability to properly integrate the various variables due to poor planning and the failure to fully utilize the fieldwork opportunities in Greece.
- The author believes that instead of running a high scale analysis of the whole country the work during the internship and field trip needed to be solely focused on modelling the problem of erosion in a much smaller scale, where the whole implication of the analysis could be explain and a much detailed conclusion could be reached. This would meant the analysis could fully grasp the conditions and physical forces interacting in a shoreline. However, this is a conclusion arrive in retrospect as the project reach its end. These conclusion aligns with some of the work done where field trips were planned to photograph and classify the environments on the shore, as shown in the image below.
- The author believes that the study of coastal areas and the various roles involved is highly important in the coming years and will serve as a key area for the development of influential methodologies, as evidenced by the many iterations of tools designed for regional-scale studies, such as **Delft3D, XBeach, and SWAN.**
- After studying the problem and gaining a holistic view of the existing solutions, the author believes there is an opportunity to develop a robust model that takes insights from mid-range applications and adapts them to the regional scale. However, this endeavor would require a much larger timeframe, deeper research, and a more focused approach than what is typically expected in a master's thesis project.

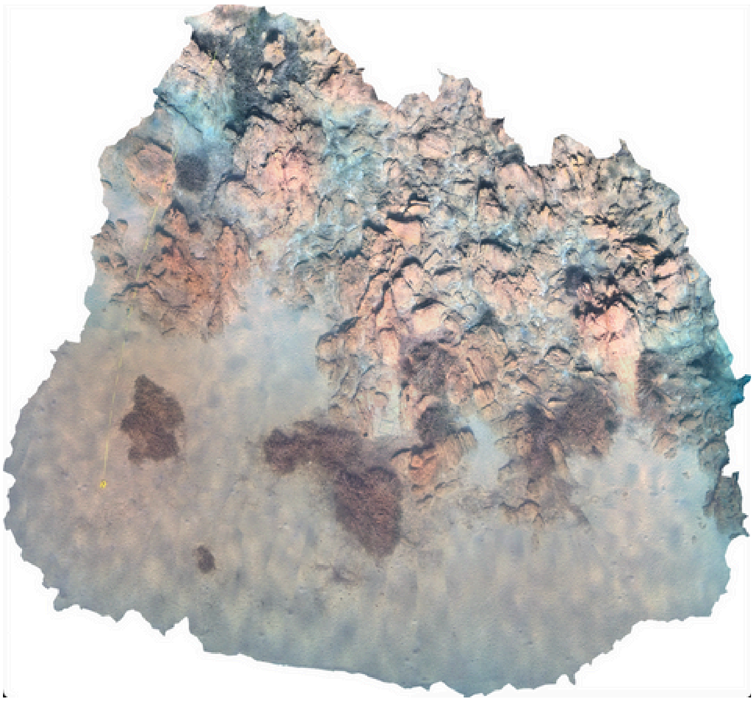


Figure 43. Ortomosaic composite of 300 gopro images for environment classification of bathymetric shoreline profile

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