Kelp forests as a coastal erosion intervention

Exploring the feasibility and awareness of using the nature-based solution of kelp forests within Chilean coasts

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MP371

TU Delft

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Exploring the feasibility and awareness of using the nature-based solution of kelp forests within Chilean coasts

by

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Preface

We are a project group of six students of Delft University of Technology who have spent the past 10 weeks working on this project in Valparaíso, Chile. Three of us are in the Master's program of Hydraulic Engineering and three are the Master´s program of Construction Management and Engineering. This is the first time we have done such a multidisciplinary project. The opportunity to experience working together abroad, meet different cultures and enjoy the time have been the key motivation.

Our initial contact with the Universidad de Valparaíso was with our supervisor, Mauricio Reyes Gallardo, whose contact information we received from a previous MDP group. During this meeting, the availability of topics were discussed and because of the enthusiasm of Mauricio, the final decision to go to Chile was made. Our project group already had a strong interest in Nature-based solutions and the chance to work on a project involving kelp as a field experiment, modelling research and social awareness initiatives made the topic even more interesting for us.

We are grateful that we, as a group, have been part of this project. We are very thankful for meeting all the people we have met during our period in Chile. All the people we met were really open to share their knowledge and show interest in our work, which we appreciate. A special thanks to Mauricio Reyes Gallardo and Patricio Winckler for guiding us through the project at the university. Milton Magnere, working on the kelp field experiment in Maitencillo, for showing us the impact of coastal erosion on different beaches and creation of awareness through public events and visits at schools. Thank you to Sebastian Correa and Jean Pierre Toledo Alvarado for helping us with modelling in SWAN and XBeach. Another special thanks to Arjen Luijendijk and Erik-Jan Houwing for their guidance from TU Delft throughout this project. There are many more interesting people we met from fisherman to modellers, a warm thank you from us all.

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Abstract

This report examines the feasibility and effectiveness of using kelp forests as a nature-based solution to mitigate coastal erosion along the Chilean coast, which has experienced significant degradation over the past few decades. Given the socio-economic reliance on stable coastal environments in Chile, particularly for industries such as fishing and tourism, addressing coastal erosion is crucial. Therefore, this study evaluates the effectiveness of the kelp forest in Maitencillo in mitigating wave height and energy flux using the SWAN (Simulating Waves Nearshore) model. Thus, this research investigates both the technical aspects of kelp application and its socio-economic implications.

Chile has many factors influencing beach states, such as storm events, earthquakes, tsunamis, climate change and sediment supply. Storm events seem to be the main driving factor behind coastal erosion, although the relative contribution of each factor remains unclear. The findings of interviews and surveys show the importance of preserving coastal areas for local communities, which would benefit economically and socially from initiatives like eco-tourism and recreation. Despite a relatively high awareness of coastal erosion among local stakeholders, there is a noticeable lack of knowledge regarding potential interventions, such as the kelp forest. This gap presents both a challenge and an opportunity for the kelp forest initiative, as it shows the need for enhanced community engagement and education to support broader implementation and possibilities for scale-up. The stakeholder analysis reveals a complicated network of relations crucial for the project's success. It is essential to keep several key stakeholders satisfied and engaged by providing evidence that the kelp forest project effectively mitigates coastal erosion.

To provide this evidence, several models have been made in SWAN. Modeling efforts using this software indicate that while the current prototype yields limited wave attenuation, enhancing the size and density of the kelp forest could dramatically improve its performance, especially during storm events—critical for addressing the predominant causes of coastal erosion. However, the models also shows that kelp already performs significantly better under storm conditions, which are the thus main drivers behind coastal erosion in Chile.

The findings indicate that kelp forests hold promise as a sustainable measure against erosion. However, scaling the project will require coordinated partnerships, adherence to regulatory frameworks, and extensive awareness-building efforts. A six-phase roadmap is proposed, detailing preparatory steps, community engagement, permit acquisition, and final evaluation measures to ensure long-term project viability. This structured approach aims to create collaboration, secure necessary resources, and ultimately provide a replicable model for using kelp forests to protect vulnerable coastlines in Chile.

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1 Introduction

1.1. Reason of project

Coastal erosion is a pressing environmental challenge that threatens both ecosystems and communities along coastlines worldwide, including those in Chile. To tackle this problem, there is an increasing interest in the use of nature-based solutions to provide sustainable and ecologically solutions. One of the solutions is the use of kelp, which has the potential to naturally mitigate coastal erosion by reducing wave energy.

This project is part of a multi-disciplinary project in collaboration with Universidad de Valparaíso And Pontificia Universidad Católica de Valparaíso in Chile, focusing on the feasibility and effectiveness of using kelp as a nature-based solution to mitigate coastal erosion in Chile. The goal is to assess the potential of kelp-based interventions not only from a technical perspective, but also considering the socio-economic implications for coastal communities that rely on healthy marine ecosystems.

1.2. Problem analysis

Coastal erosion is a pressing issue for Chile, where strong waves, storms, and rising sea levels threaten shorelines, affecting its infrastructure and local communities. This issue is particularly critical for coastal communities reliant on fishing and tourism, as erosion damages structures and reduces economic opportunities.

Nature-based solutions, like kelp forests, offer an alternative that intents to the stabilize erosion of coastlines. Kelp could potentially attenuate wave energy and promote biodiversity at the coastlines. However, effectively using kelp as an erosion intervention in Chile requires addressing both technical challenges as socio-economic considerations. The technical efficiency and effectiveness of this intervention is still rather unknown. As of now, a prototype kelp forest is being built in front of the coast of Chile to assess the effect of the kelp on wave attenuation in a real life scenario, but this is not finished yet. Moreover, the effects of the kelp forest have never been investigated using a model. An additional benefit of using a model is that certain properties can be changed, which is very beneficial to investigate, especially if the kelp forest is to be expanded to other locations in front of the coast of Chile. As for the socio-economic considerations, challenges could arise in achieving community support for the intervention and the potential impacts on the local economy. This project aims to assess how kelp-based solutions can be feasibly and technically, sustainably and socially implemented, while still being feasible, to address coastal erosion in Chile.

1.3. Objective

The main objective of this report is to address the research question: “How can kelp be effectively applied as a nature-based solution to mitigate coastal erosion in Chile, considering both technical feasibility and socio-economic factors?” The technical feasibility will be tested by answering the question: ”What is the effect of kelp forest characteristics on the wave height, the wave energy flux and the energy density spectra, under different wave conditions?”. The socio-economic objective is creating awareness around the importance of marine algae, conducting a comprehensive stakeholder analysis and developing a roadmap for scaling up kelp-based interventions. The key aim of the project is to create a positive feedback loop for building kelp forests that mitigate coastal erosion.

1.4. Thesis outline

The report begins with a description of the methodology used throughout the project. This is followed by a background section about coastal erosion in Chile. The scope of the project is also defined, clarifying objectives, boundaries, and key assumptions. Next, the application of kelp as a nature-based solution is explored, examining its potential to mitigate coastal erosion. The project then addresses local awareness and perceptions of coastal erosion, drawing on survey and interview findings to understand the views of community members, fishermen, and local businesses. A stakeholder analysis is conducted, identifying key stakeholders, their levels of interest, influence, and potential roles in the kelp project. Subsequently, the technical feasibility of the applying kelp is tested by means of several SWAN models. In these models, the influence of design choices will be assessed. This is followed by a roadmap for scale-up, outlining recommendations for future expansion, potential funding sources, policy considerations, and strategic partnerships to ensure long-term project sustainability and success. Finally, conclusions will be drawn about the application of kelp to prevent erosion, followed by a short discussion.

2
Methodology

This chapter defines the research methods and explains their relevance by detailing how they will help to answer the main research question stated in Chapter 1.

This project researches kelp-based solutions to mitigate coastal erosion. To achieve this, the research will follow a structured methodology that encompasses background research, stakeholder analysis, scope definition, explanation of kelp-based solutions, awareness assessment, modeling, roadmap to scale-up, conclusion and discussion.

The research starts with consulting background information to provide a comprehensive understanding of coastal erosion in Chile, by exploring its extent and causes, the implications for affected areas and the current lack of awareness regarding coastal erosion in Chile. The knowledge is gained through meetings with various professors and researchers at the Universidad de Valparaíso, literature studies and site visits to Chilean beaches. Providing a clear understanding of coastal erosion is an essential part of this project, since it is very important to fully understand the problem before being able to find a solution to it. Different hypotheses to why there is so much erosion are discussed and thorough background information about the Chilean coastline is given. Visits to various coastal areas affected by erosion have been planned and the physical effects of erosion on beaches and infrastructure are documented, as well as observations of local environmental conditions,

The project will then zoom in further on two beaches. These areas will be the scope of the project. The hydrodynamic, morphodynamic and socio-economic aspects of the beaches will be discussed in detail to give the reader a better understanding of the beaches that will be researched throughout this whole paper. A model will be made of only one of the two beaches for which the hydrodynamic and morphodynamic characteristics are of importance for setting up the model.

Once the scope is defined, the paper dives further into the kelp themselves and the application of it. It explains what type of kelp is used and what the kelp forest used in the field experiment looks like, and what other numerical research has already be done in his project. It is then defined which role this model will fulfill in the bigger scheme of the project.

An essential part of the research is to assess the level of local awareness regarding coastal erosion and the kelp forest solution to mitigate coastal erosion. This information will be obtained through semi-structured interviews with large organisations and surveys with local people and businesses. Surveys are used which consist of statements which respondents have to rank and open questions, in which more in-depth questions regarding coastal erosion and the kelp forest project are asked. These surveys will be analysed using a statistic program, called SPSS. Within this statistical analysis, the different demographic aspects of the respondents will be explored. Also, a factor analysis is used to create a set of statements which describe a certain attitude towards coastal erosion. From there on, the influences of different aspects are explored to the level of awareness on coastal erosion by local stakeholders. The level of awareness is important to determine the level of support for the solution, the gaps in understanding, factors that could influence stakeholders' support and to study how the kelp-based solution can possibly be further extended in the future.

The next step is to identify and analyse the stakeholders involved in the kelp project. Therefore, different stakeholder analyses will be used. The first step is to get an overview of all the different stakeholders involved, such as governments, local businesses, local communities, industries and environmental NGO's. Second, a power-interest-attitude grid will be created to categorise stakeholders based on their level of influence, interest and attitude. This analysis will help in assessing the role

of each stakeholder in addressing erosion and implementing mitigation strategies. Finally a relations between the actors will be mapped in a relationship diagram.

The paper's next section will concentrate on the technical aspect, as it is dedicated to modelling. The purpose of the modelling part is to demonstrate how the kelp affects waves within the given scope. This section will first outline the goal of the model and what specific waves are looked at. The goal is followed by a thorough explanation of the input parameters and required equations, which helps the reader comprehend how the models function.

Prior to examining the results of the models and formulating conclusions, several hypotheses are formed. Subsequently, the results will show what the actual effect of the kelp is on the waves, by looking at the wave height attenuation and wave energy flux reduction. The hypothesis and results will then be reviewed and contrasted with each other in the chapter's modelling conclusion after which a discussion on the modelling part will follow in the last chapter of the paper as a whole, stating flaws of the models and other important notes.

The paper will conclude with a scale-up analysis of the kelp forest project. The opportunities and threats, of scaling-up, in terms of environmental, economic, social and cultural will be discussed. Potential collaborations and partnerships will be analysed, such as with the local community, municipal and government bodies, private companies and (international) research institutions. This will conclude with a recommendation on how best to scale up and with whom to collaborate, and will end with a roadmap to success.

3

Background information

This chapter addresses the background information regarding coastal erosion. It helps explain the need for a solution like the kelp forest.

Before diving into coastal erosion and its causes, it is important to keep in mind the geographical differences between Chile and Europe, where the focus of attention in engineering often lies.

Chile is Located on the east side of the Pacific Ocean. The presence of this big ocean has its consequences on the coastal climate of Chile. In general, the swell waves have a very developed shape (i.e. low and long), due to their origin being far away. Besides the difference in oceanic scale, the alongshore length scales are totally different as well. The Chilean coast is approximately 4,000 [km] long, which is a continental length scale in Europe (see Figure 3.1). Therefore, natural phenomena and landscape changes may differ greatly from place to place along the Chilean coastline.

Figure 3.1: Difference in scale between Chile and European countries (*Google Earth*, n.d.)

3.1. Cause of erosion

Research has shown that 80 % of the Chilean beaches has eroded over the last four decades, while 7 % has accreted and 13 % has remained stable. This clearly shows that there is an erosive trend going on. The erosion can have many causes, with the most logical ones being sea level rise, a changing wave climate, earthquakes, tsunamis and a change in sediment supply (MARTINEZ, Winckler, Agredano, Esparza, Torres, & Contreras, 2021). These potential causes will now be addressed on by one.

3.1.1. Sea level rise

Over the past few decades, the amount of sea level rise (SLR) has been relatively small in the Chilean oceanic waters. Because of ENSO circulations (El Niño and La Niña), fluctuations of around 30 [cm] have been observed, but there is no significant trend visible yet in the sea level development over the past decades (Martínez et al., 2017). However, these results could be contaminated by uplift of the Chilean mainland caused by tectonic activity. This is because the Nazca Plate, on the west side of

South America underneath the Pacific Ocean, is slowly moving underneath the South American Plate (see Figure 3.4). This movement causes uplift of the South American Plate. This process is visualized in Figure 3.2.

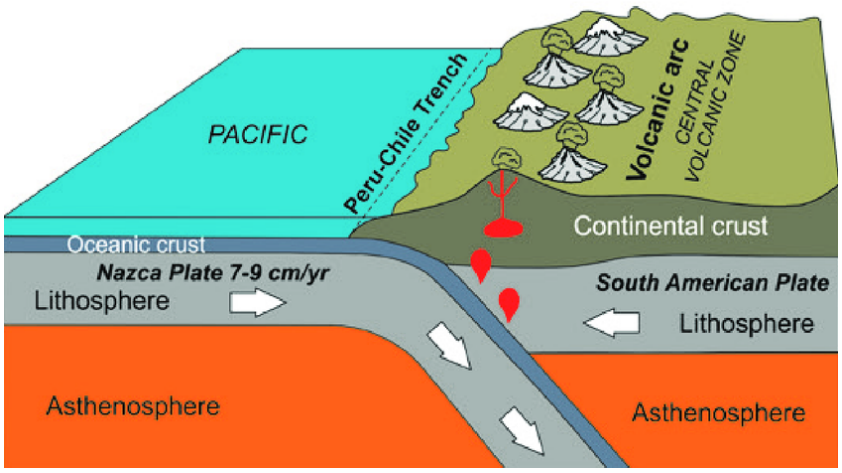


Figure 3.2: Tectonic movement of the Nazca and South American plates (*Sketch of subduction zone in the Central Andes, southern Peru (USGS,... | Download Scientific Diagram*, n.d.)

If the reference level of the mean sea level (MSL) is located on land, but the land elevation is changing as well, the MSL is not reliable anymore without accounting for uplift or subsidence. As there is no conclusive data that can quantitatively tell the amount of subsidence or uplift, past SLR remains unknown. However, globally the MSL has increased by around 10 [cm] over the past 30 years. This is likely to be roughly equal to the SLR near Chile (*Climate Change: Global Sea Level*, n.d.). This amount of SLR will definitely have contributed to coastal erosion. Its sole effect has not been investigated, however.

Future SLR might be even more important to consider. (MARTINEZ, Winckler, Agredano, Esparza, & Contreras, 2021) used RCP 8.5 scenario of the IPCC framework to assess the effects of SLR. This is a conservative scenario of the Intergovernmental Panel on Climate Change, which assumes a business-as-usual situation where no climate mitigation is happening. This yields large amounts of erosion: an average of 53 [m] coastal retreat is expected at the analysed Chilean beaches by the end of the century, driven by a SLR of 0.58 [m]. One should note that this amount of SLR could be compensated or aggravated by tectonic uplift or subsidence respectively.

3.1.2. Changing wave climate

Another important contributor to coastal erosion in Chile is the changing oceanic wave climate. Martínez et al. (2017) showed that the occurrence of extreme storm events increased dramatically over the past few decades. An extreme event is defined as an event during which the significant wave height exceeds the mean wave height by two standard deviations. The occurrence of these storms used to be 5 times per year in the middle of the last century, but nowadays the number of extreme events is approximately 20 per year (see Figure 3.3). The storms cause massive amounts of erosion. In August 2015, a series of three storms caused a beach retreat of 30 [m] at Reñaca Beach. This beach recovered quite fast to its original state, though. Caleta Portales Beach however, retreated 20 [m] and did not recover. So these cases are quite contradictory. There is no clear evidence that shows that the increase in extreme events causes coastal erosion on the long term, but it is very plausible to be one of the causes.

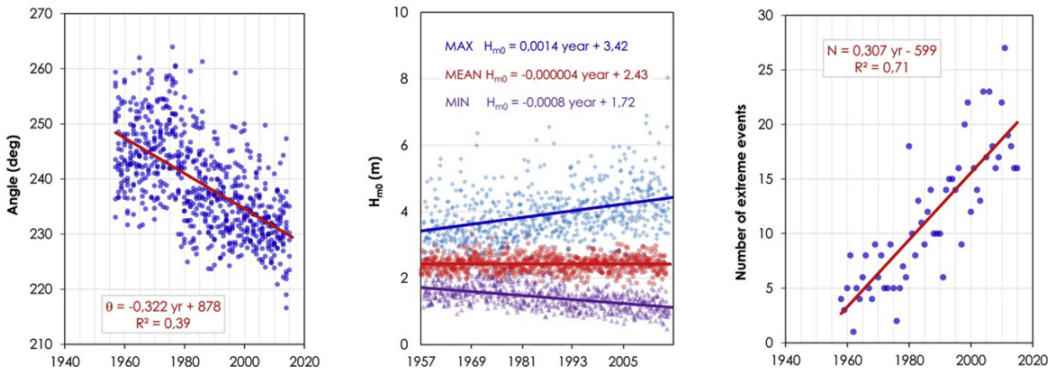


Figure 3.3: From left to right: Development of monthly mean wave direction at Valparaíso; Monthly mean, maximum and minimum significants wave heights at Valparaíso; Annual frequency of extreme events (Martínez et al., 2017)

One could argue that storms should not cause structural erosion, as over time the beach should have a 'dynamic equilibrium', assuming a normal coast profile. The Chilean coast however, has a very steep profile with a deep trench not far from the coast, the so-called Peru-Chile Trench (see Figure 3.4). The trench runs from the south of Ecuador to central Chile with a length of 5900 [km]. The maximum depth is about 800 [m]. This trench could, together with a steep nearshore bathymetry in general, be the reason why so much sediment seems to be lost during storms. It vanishes in the trench during storms and cannot return to the shore under calm conditions.

Figure 3.4: Nazca Plate, South American Plate and Peru-Chile Trench (*Andes: Collision of Oceanic and Continental Plates - A Learning Family*, n.d.)

In addition to an increase in extreme storm events, the study of Martínez et al. (2017) also showed that the mean wave direction offshore at Valparaíso changed throughout the years (see Figure 3.3). This is caused by the South Pacific Anticyclone. As the change in mean wave direction redistributes sediment along the shore, the hypothesis is that it will cause erosion at some locations and accretion at others (see Figure 3.5).

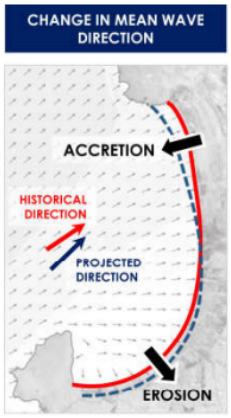


Figure 3.5: Hypothesis of changing wave direction on shoreline (Winckler et al., 2023)

3.1.3. Earthquakes

Chile has a leading-edge coast, because the majority of the country is on the border of two converging plates. They are characterized by a lot of tectonic activity and a narrow continental shelf. The oceanic edge of the Nazca plate converges with the continental edge of the South-American plate. Because of this, earthquakes are a common phenomenon in Chile. During these earthquakes, the South American plate is uplifted relative to the Nazca plate (see Figure 3.2), although subsidence of the mainland also may occur at some locations (Aedo et al., 2023). The uplift will disturb the equilibrium of the shoreface profile and cause accretion, according to Bruun's rule (Anthony & Aagaard, 2020). In conclusion, earthquakes are not contributing to coastal erosion. In contrary: they mostly induce accretion.

3.1.4. Tsunamis

Following a big earthquake in the ocean, naturally a tsunami will follow. These phenomena, with often catastrophic consequences, are interesting to consider in view of coastal erosion. MARTINEZ, Winckler, Agredano, Esparza, Torres, and Contreras (2021) concluded that tsunamis do not play a significant role on decadal-scale shoreline changes. They cause large amounts of erosion on the short term, but the affected beaches usually recover quickly to the original state. La Serena beach for example, initially retreated by 100 [m] during the Illapel earthquake on the 16th of September 2015, but quickly recovered to its initial state in the following months. There are also cases where a tsunami did have a big impact on the beach state. At Santa Domingo beach, the slope and grain size changed dramatically during the tsunami on the 27th of February 2010 (*"Si entendiéramos los procesos de la naturaleza, no tendríamos desastres": La mirada de dos geógrafos a 10 años del 27F | Ladera Sur*, n.d.). However, no cases with structural erosion caused by a tsunami are known.

3.1.5. Change in sediment supply

Finally, a change in sediment supply from rivers could influence the beach states on the Chilean coasts. Interventions like dams and (illegal) sand mining heavily influence the sediment supply from rivers. Between 2009 and 2020, La Serena beach retreated by 0.3 [m/year]. This is most likely due to the combination of sand mining and the construction of the Puclaro Dam in 1999 in the Elqui River. 2.29 $\times 10^6$ $[m^3]$ has been mined in those years and the dam had accumulated 0.77 $\times 10^6$ $[m^3]$ by 2018. In addition, large-scale illegal sand extraction from the Aconcagua River is likely a major cause of erosion at Concón Beach. However, due to the lack of precise data, it is too early to establish a definitive causal link ((MARTINEZ, Winckler, Agredano, Esparza, Torres, & Contreras, 2021)). As there is not much data on sediment transport in Chile, the degree to which changes in sediment supply influence coastal erosion on a greater scale is hard to assess.

3.1.6. Conclusion

Some of the previously mentioned possible causes of coastal erosion do actually not play a big part in it. Where there is no proof that tsunamis cause large-scale erosion, earthquakes even tend to counteract the consequences of erosion, by inducing uplift and subsequent accretion. On the other hand, climate

change does seem to play a big part in the erosive trend. SLR has not yet happened to a large extent, but its exponential character makes it a realistic reason of coastal retreat in the next decades. In addition, the increasing amount of extreme storms appears to play a large role in the erosion over the past years and decades, with the Peru-Chile trench causing loss of sediment to the ocean. The changing mean wave angle also causes erosion locally. Finally, the reduction of sediment supply from rivers also forms a reason of the coastal retreat.

In conclusion, there are several reasons for the erosion that has happened in Chile over the past decades. Due to a lack of research and data, it is hard to say to what extent each cause is responsible for the erosion. What is clear is that the future does not look bright, with the consequences of climate change that are only becoming stronger. Therefore action needs to be taken now, to make sure Chilean beaches can be preserved.

3.2. Negative impact

Chile is very dependent on its coast and seaports, as its economy relies heavily on export. 31.1 % of Chile's GDP consists of export (*Exports of goods and services (% of GDP) - Chile | Data*, n.d.). Therefore, the seaports should and shall be protected. However, in recent years, urban areas have also expanded very close to the coast. This makes the area that has to be protected unnecessarily large.

Building as close to the shore as has been done recently also makes the possibility of coastal retreat impossible. This would cause damage to the built environment. There are now only two acceptable options left. The first is that beaches are lost, but coastal retreat is limited to only the beaches; buildings are preserved. Option 2 is that measures will be actively taken to maintain the beaches.

3.3. Impact of coastal erosion on coastal landscapes

As elaborated, coastal erosion is an important matter at Chilean beaches which results in a change of structures and landscapes. Moreover, since coastal erosion leads to beaches being eroded, the surroundings of these beaches are affected as well. The images (see Figure 3.6) of Martínez et al. (2017) show how the sea at the Caleta Portales beach in Valparaíso has taken over the beach and that it has moved land inwards after a big storm in 2015. Due to the water moving inland, beaches disappear gradually until fully being taken over by the shoreline. Consequently, coastal erosion results in the disappearance of beaches at Chilean coasts. Research led by the Joint Research Centre of the European Commission shows that half of the beaches worldwide could potentially disappear due to coastal erosion by the end of the 21st century (EuropeanCommision, 2020).

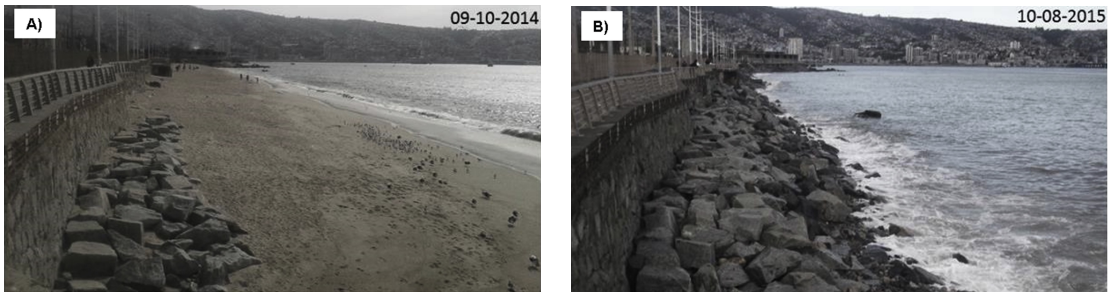


Figure 3.6: Caleta Portales beach in Valparaíso after the big storm in 2015 ((Martínez et al., 2017))

Nevertheless, not only does the coastal erosion result in disappearing beaches, it also results in the loss of defense for the waves to reach the land. Therefore, the built environment and local infrastructure are at risk of being eroded as well. Beaches play a vital role as a barrier for waves and their impact, making sure that the wave energy gets lost and shocks are attenuated (Aimone Arredondo, 2020). The results of this loss in defense can also be seen in the images (See Figure 3.7) of Martínez et al. (2017). Here, it can be argued that the structures are heavily damaged due to the clashing of the waves.

Figure 3.7: Damaged structures at Chilean beaches (Martínez et al., 2017)

Another important aspect with coastal erosion taking over landscapes and structures is the construction distance from buildings and infrastructure being close to the shore. Chilean urbanization and tourism is evolving rapidly in coastal zones, thus Ibarra (2024) states that construction close to coasts should be avoided, due to the society being exposed to erosion risks (Alegría Flores, 2024).

Furthermore, research performed by the CIGIDEN (2023) shows the urge of implementing coastal policy for integrated coastal management, controlling the construction in coastal zones. Additionally, the research stresses that the fast growth of tourism in the coastal zone results in construction in coastal zones which are endangered by ecological vulnerability.

3.4. Awareness of coastal erosion

Despite coastal erosion causing negative impacts on urban coastlines, disrupting economic activities and hindering sustainable development, it is still not regarded as a recurring hazard in Chile. According to Martínez et al. (2017), this may be due to coastal erosion being overshadowed by other natural events like earthquakes, tsunamis, and the El Niño-Southern Oscillation. Research in this area therefore lacks a systematic approach, resulting in limited and fragmented knowledge.

Additionally, previous research performed by a TU Delft MDP team, showed that the environmental awareness and knowledge among the Chilean population is generally rather low. This is intensified by extreme events like tsunamis and earthquakes that create unpredictable coastal dynamics. Also, Chile's steep, rocky shorelines differ from regions where soft solutions are commonly applied, making local research essential but scarce. Moreover, there is a conservative mindset in both private and governmental sectors, favoring hard structures over innovative solutions, which limits trust in alternative, nature-based approaches. Lastly, a lack of collaboration and communication between knowledge institutions, government bodies, and local stakeholders further hinders awareness and implementation of nature-based solutions. (van Batenburg, van Heijningen, Hoogendoorn, Klarenbeek, & Ridderinkhof, 2019).

3.5. Kelp forest project

The essence of this report revolves around the ongoing kelp forest project in Maitencillo. All information below is acquired through one of the project members; Milton Magnere (Magnere, 2024). Since coastal erosion can be regarded as an impactful problem at the coastline of Chile, a project team of 10 engineers has implemented a possible intervention for this occurrence. Moreover, this project team derives from a collaboration between the Universidad de Valparaíso and the Pontificia Universidad Católica de Valparaíso. The aim of the project is to investigate whether the planting of kelp within the ocean would

result in the reduction of wave intensity. This phenomenon is investigated to see whether building with nature can be used to mitigate coastal erosion in coastal areas.

To achieve this goal, so called kelp forests are being implemented to the bottom of the ocean. In order to create these forests, a kelp farming station has been set up where a specific type of algae is harvested until it reaches a certain size. When the kelp reaches this desired size, it is tied to different ropes and attached to a concrete block into the ocean. As for now, the kelp forest is only implemented at a section of the Caleta beach in Maitencillo, which is a coastal town of the municipality of Puchuncaví.The usage of kelp as a solution derives from the history of the beaches in Chile. In the past, there were many different kelp forests present in the sea, close to the coastline in different regions in Chile. However, due to the value of kelp for retail and other purposes, most of the kelp forests have been harvested, resulting in the disappearance of the kelp within the water.

Figure 3.8: Kelp farming station

For now, it can not yet be confirmed to which extent the kelp forest will have the desired effect in terms of mitigating coastal erosion. However, this project does have the potential to scale up to different other coastal areas if successful. Therefore, this project will delve into which aspects would play an important role in up-scaling the project.

One important aspect of the project is the current regulations which apply for these types of projects in Chile. As for now, the regulations state that the coasts of Chile are owned by the Chilean Armed Forces and specifically by the marine navy. However, the Chilean Armed Forces have divided the ownership of specific parts of the sea to the local fishermen. In Chile, certain sections of the coastline have been designated as AMERB areas. In English this stands for Benthic Resources Management Areas. AMERB areas are subjected to the allocation of exclusive exploitation rights to artisanal fishing organizations. This is done through a management and exploitation plan for the resource, based on the conservation of benthic resources present in previously geographically delimited geographic sectors (Fecha de Publicación, 2021). Meaning that fishing organizations have ownership over the sea bottom and the living species on it. This does not include the fish that swims within this area but does include scallops and kelp. Therefore, these fishermen are in charge of what happens on their own land and thus have a say in whether the kelp forest project can be implemented on their land.

Due to this regulatory system and the uncertainty of the working of the project, it was not possible to get a permit for this kelp forest project on a large scale. The process of applying for this type of permit could take approximately 10 years. As for the project at Caleta beach, an experimental permit

was granted to implement the project in this specific area. Moreover, the local fishermen association therefore owns the project and the experimental permit was granted.

Another important aspect of the project is the current funding. The initial funding was granted by the government and was US$200,000 to start the project. However, in order to scale up the project, more funding is required since the kelp forest does not directly result in any money and resources are needed for implementation.

Finally, one last important aspect for potentially scaling-up the project is the perspective of different stakeholders regarding the project. Especially local stakeholders have an important role in regard to how they would experience the kelp forest in their hometowns. Currently, the project has only been set up in Maitencillo and the attitude of the local stakeholders has been experienced by the project team. Here, the observations were made that a part of the local stakeholders is not aware of coastal erosion in the first place and therefore do not see the importance in the project. In order to scale-up the project, local support and awareness are essential to create collaborations, as well as with non-local stakeholders.

4

Scope

This chapter will address the scope of this research. The scope will focus on two beaches: Papagallo beach and Caleta beach. First, the rationale behind selecting these two beaches is discussed. In the sections after, the hydrodynamics, morphodynamics and social characteristics are described. The social characteristics consist of the demographic aspects and the economic industries.

4.1. Reasons of selection

Two beaches are considered: Caleta beach at Maitencillo and Papagallo beach at Quintero. Important to note is that the social aspects will be considered for the whole area of the towns of Maitencillo and Quintero. The hydrodynamics and morphodynamic characteristics solely focus on the beaches.

In front of Caleta Beach, an artificial kelp forest is being installed, which is further described in Chapter 5. The beach in question was selected for the project on the basis of two principal considerations. First of all, a beach had to be chosen that experiences erosion in order to see whether the kelp forest reduces erosion. According to MARTINEZ, Winckler, Agredano, Esparza, Torres, and Contreras (2021) Caleta beach experiences erosion rates between 0.2 and 1.5 [m/yr].

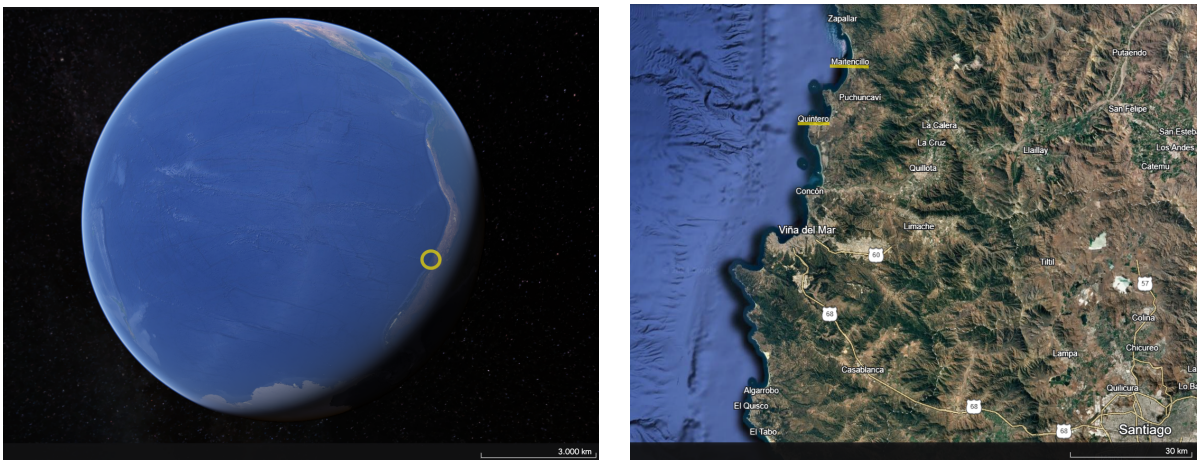
The second reason is that there are local stakeholders from Maitencillo that are already in compliance with the project. Therefore, it is useful to assess stakeholder involvement in Maitencillo. As has been explained, the fishermen hold ownership over the sea bottom. The fishermen who have ownership over the sea bottom at Maintencillo have previously participated in kelp-related projects. As a result, they were well-informed and more willing to contribute to the project.

Papagallo beach is the perfect example to show how removing kelp could potentially lead to a lot of beach erosion. Papagallo used to be a broad beach with a very large kelp forest in front of it. In recent years the kelp forest has been harvested to make profit out of (*Interview with Milton Magnere*, 2024). Interestingly, this led to a lot of erosion, as the wave energy is no longer reduced by the kelp and can now reach the beach.

The sections below describe the social, morphodynamic and hydrodynamic characteristics for each beach. It is important to understand these aspects, because the whole system affects the equilibrium of the coast line. Both sites are located close to each other, with a straight line distance of only 17 [km]. Therefore, a lot of the offshore hydrodynamic characteristics are considered the same.

4.2. Hydrodynamics

The Chilean coast is connected to the Pacific Ocean, which covers half of the Earths surface. To give an impression, Figure 4.1 (a) shows the size of the ocean and the Chilean research area marked by a yellow circle.



(a) (b)

Figure 4.1: (a) Size of the Pacific Ocean (b) Location of Maitencillo and Quintero (Google Earth)

Figure 4.2 shows the wave climate in front of the coast of Maitencillo. Even though Chile has a very long coast, not a lot of research has been done to investigate the waves arriving at this long coast (Beyá, Álvarez, Gallardo, Hidalgo, & Winckler, 2017). The wave information that will be used for Caleta beach comes from Atlas de Oleaje de Chile. This information was generated with the Wavewatch III wave model and has been calibrated. It is expected to be useful for researchers and engineers who are concerned with the wave climate (Beyá et al., 2017).

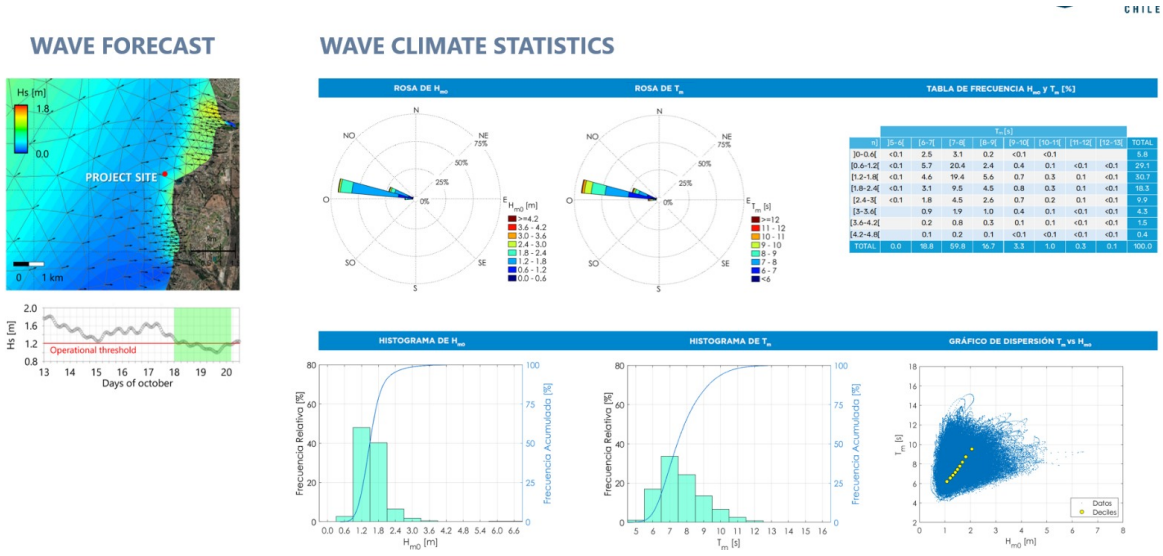


Figure 4.2: Wave climate statistics at Caleta beach
(Oceanica & de valparaiso, n.d.)

As can be seen from H_{mo} histogram in Figure 4.2, the mean significant wave height is 1.6 [m]. From the T_m histogram can be found that the mean wave period is 7.5 [s], corresponding to typical periods of swell waves. The predominant wave direction is NWW. The spectral peak value, γ, of the Jonswap spectrum is 1.42 for this location. (Oceanica & de valparaiso, n.d.).

In Chapter 3.1.2 it was mentioned that the direction of the wave climate is slowly changing towards the south. This should be taken into account when modeling the site since the forest is expected to also mitigate erosion in the future, not just now.

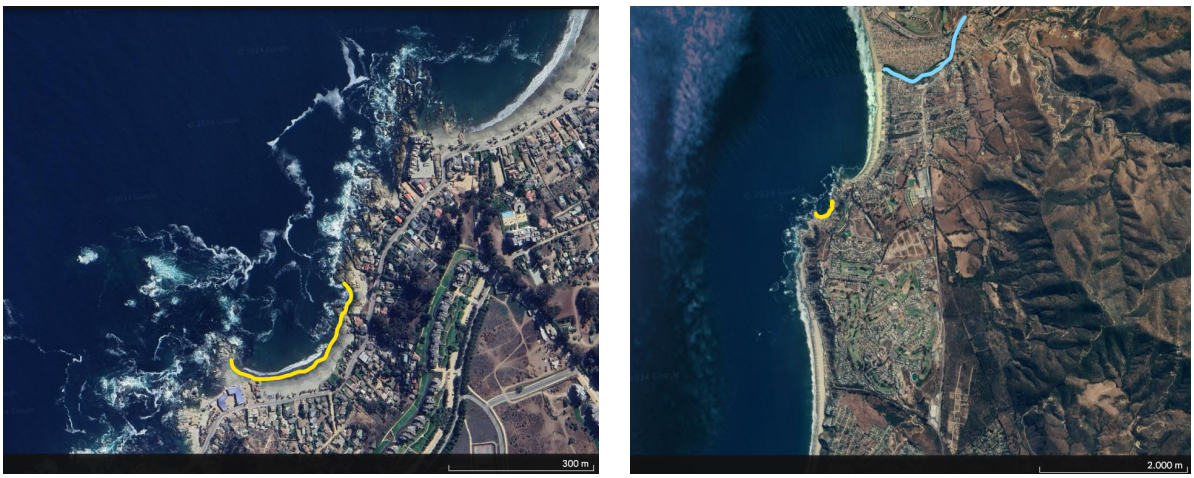
The wave conditions in Papagallo are found using the same node in the Olas Chile database as Maitencillo. Hence, the wave conditions used for Maitencillo and Papagallo are the same. This makes the two beaches even more easy to compare.

4.3. Maitencillo

In this section, the morphodynamics and social aspects will be discussed accordingly.

4.3.1. Morphodynamic Characteristics

The beach at Maitencillo is called Caleta beach and is located at 32°38′54″S. In Chapter 4.2 it is mentioned that the wave climate is predominantly characterised by swell waves. These are relatively low and long waves and have an almost constant wave height, hence they give a relatively narrow sandy littoral zone. In Figure 4.3 the coastline of the site is shown. The coast lies between two rocky headlands reaching in the ocean and where there is no sediment source connected to this beach. On the North, Estuary Catapilco can be found which is connected to a dry river. It is expected that even after rainy days the sediment can not reach Caleta beach because of the large headlands at each side of the beach. Between the surface and a depth of 12 [m], the bottom consists mostly out of rocks. When going deeper, predominately sand can be found. On these rocks, a small amount of kelp is already present. The AMERB has a natural density of 0.599 $[u/m^3]$. (Pontificia Universidad Católica de Valparaíso, 2023)



(a) (b)

Figure 4.3: (a) Caleta beach (b) Caleta beach in yellow; North Estuary Catapilco (Google Earth)

4.3.2. Social Characteristics

Demographic aspects

To gain a deeper understanding of the selected areas, the demographic characteristics of each region will first be examined.

Maitencillo is a small town in the Puchuncaví commune, in the Valparaíso region and has a population of approximately 1300 inhabitants (EcuRed, n.d.). Due to Maitencillo's small size, available information is limited to the municipality of Puchuncaví (which includes Maitencillo). The average amount of years of education is only eight. From data of the Biblioteca Nacional de Chile, it can be seen that most children do follow the basic education. However, only 30.2% of these scholars continue with secondary education or higher. The average monthly income is $1,550 per person (Arévalo González & Benavides Gómez., 2013). This is slightly below the national level, which is $1,850 per month (Uppala, 2024).

Economic activities

As for the town of Maitencillo, the area is known for having a good economical wellbeing and is mainly centered around tourism. Additionally, most dwellings are not permanently inhabited, in 2012, only 38.7 % of the dwellings were permanently inhabited. As for the other dwellings, these are mostly used during the summer season (Benavides Gómez, 2013). Therefore, an important source of employment in Maitencillo is providing touristic services. Moreover, the touristic activities mainly involve the coast of the town such as watersports and hospitality at the beach. Furthermore, a field trip to the town showed that the businesses close to the beach consist mostly of diving schools, surf schools and

restaurants. However, the biggest employment sector within the town is industry (22.6%), followed by accommodation and food services (18.6%), and with the public administration and defence (18.3%), ranking third. (BCN, 2023).

4.4. Quintero

In this section the morphodynamics and social aspects of Quintero will be discussed accordingly.

4.4.1. Morphodynamic characteristics

El Papagallo beach in Quintero is located at 32°46′46″S in between two rocky headlands reaching into the ocean. The nearest sediment supply in the region is of the Aconcagua river, 15 km to the south, and the Campiche inlet, 6 km to the north. When sediment is transported towards or away from El Papagallo beach, it falls into the deep water Peru-Chili trench when following the headlands. This causes El Papagallo beach to be a bay in dynamic equilibrium where no net sediment transport is happening. The sediment that is present has it's origin in local weathering. Decades ago, the beach used to consist of a rocky bottom and vegetation of kelp, dissipating the wave energy and trapping sediment. Since the removal, the beach has eroded 13964 [m²] of sand in the period 1980 - 1994. This caused is a 2 [m/year] retreat. The waves can now penetrate all the way towards the shoreline causing sediment to be transported offshore *Interview with Milton Magnere* (2024). Ripples can be found at the bottom of the seabed indicating wave dominance. An increase in average diameter with depth is found, which indicates erosion of the surface sediment as a result of the action of the waves.

(a) (b)

Figure 4.4: (a) Playa El Papagallo (b) Playa El Papagallo in yellow; North Campiche Estuary, South Aconcagua river in blue (Google Earth)

4.4.2. Social Characteristics

Demographic aspects

To gain a deeper understanding of the selected areas, the demographic characteristics of each region will first be examined. Quintero, a larger town also located in the Valparaíso region, has a population of 33,800 residents. It has therefore its own municipality with its own data and information. The percentage of students enrolled in secondary education in Quintero is slightly higher than in Puchuncaví, at 38.8%. Lastly, the average income per person in Quintero is chil$1.625 per month (de Quintero & de Valparaíso, 2020). This is slightly higher than in Maitencillo, but still remains below the national average.

Economic activities

In Quintero, the largest employment sector is by far the industry companies (40,1%). The second largest sector is the public administration and defence (12,6%), followed by motor vehicle repairment companies (9,0%). (BCN, 2021). Tourism is a growing sector in Quintero, especially for recreational

sports like surfing and diving, it becomes more popular (Rangel-Buitrago, Contreras-López, Martínez, & Williams, 2018). However, the industrial park of Quintero Bay (QB) in the central coast of Chile is located along approximately five kilometers bordering the sea and covers an area of around 500 hectares. It was established in the 1960s and presents high levels of pollution due to the industrial activity, and therefore it is known as one of the five Chilean “sacrifice zones” (Oyarzo-Miranda et al., 2020). The industrial bay was intended to displace the agricultural and fishing activities in the area. The state’s aim was to create an industrial hub to support the development of the mining industry in the central area, and among the geographical and economic reasons given for its location were the availability of water, the proximity of the ports of Quintero and Valparaíso, and the location of the mining centres and projects.

The industrial park is currently made up of more than 15 polluting sources dedicated to energy generation with thermoelectric plants; copper refining and smelting; storage and distribution of gas and oil fuels and chemical substances, as presented in figure 4.3. In addition to these large private and public companies, there is a whole network of services that operate alongside the industrial port, such as rail transport, truck freight transport, maritime agency with port service and comprehensive docking, among others (González, 2022).

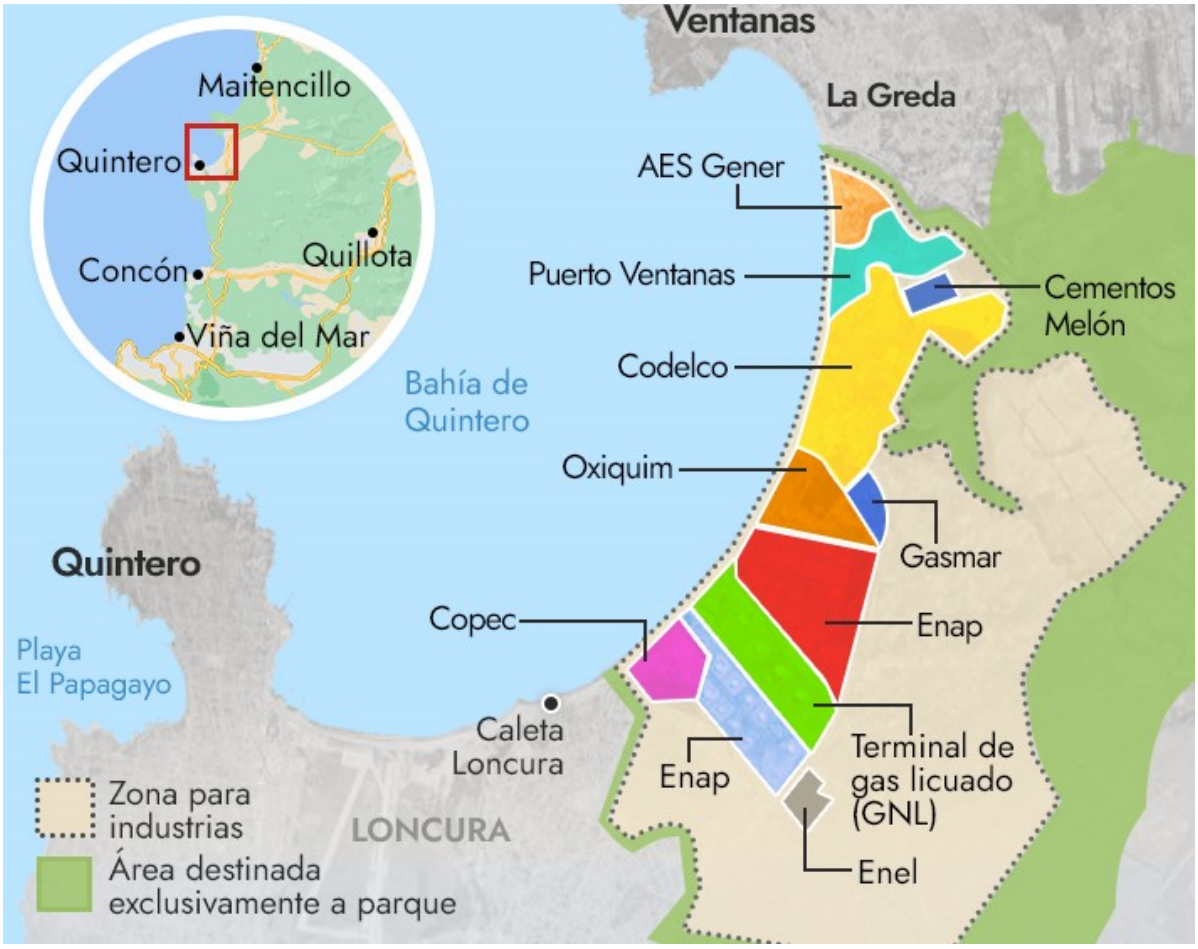


Figure 4.5: Map of the industrail zone Quintero ().

5

Application of kelp

The aim of this chapter is to explain how kelp is used to mitigate coastal erosion. It first addresses which type of kelp is used at Maitencillo and why. Then, the protype is described in more detail. To better understand this project it is important to understand what has already been investigated using numerical studies. This is explained in the last part of this chapter.

5.1. Macrocystis Pyrifera

The specific kelp used in this study is Macrocystis Pyrifera, also known as giant kelp. This species grows in rocky environments, also along the coast of Chile. The ecosystem will therefore not be negatively affected by an alien species. The species provides a place for refuge, spawning and food for a varied fauna of invertebrates and fish. It is also very important in slowing down the deoxygenation and acidification of oceans by performing photosynthesis (Pontificia Universidad Católica de Valparaíso, 2023).

Giant kelp has its name for a reason, under ideal conditions it can grown up to 53 [m] at a rate of 50 [cm/year]. Gas-filled bladders at the base of the leaves cause the kelp to grow upwards toward the surface (SIMoN, n.d.). The anatomy of the kelp is visible in Figure 5.1.

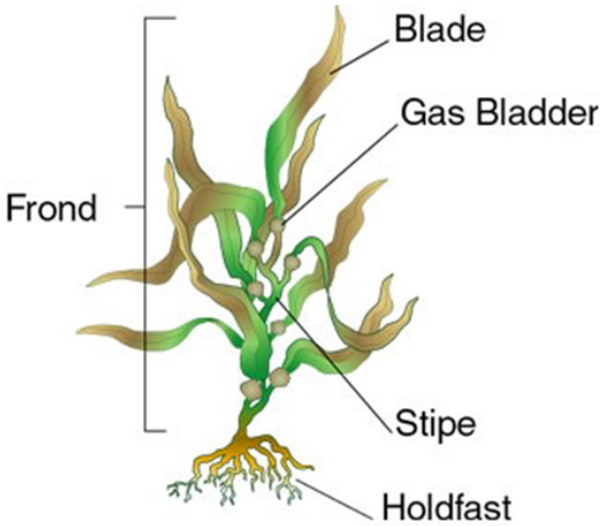


Figure 5.1: Autonomy of giant kelp (McBride, 2013).

A vegetated foreshore can potentially be used to reduce the impact of storm surges. Kelp growing near the shore prevents beach erosion by dissipating the wave energy due to depth-induced wave breaking, bottom friction and wave attenuation, creating a stable foreshore (Vuik, Jonkman, Borsje, & Suzuki, 2016).

5.2. Prototype of the Kelp Forest

The basis of the prototype are concrete blocks with a special and patented shape, located at the corners of the red squares as seen in Figure 5.2. In between these rocks, 4 main ropes are stretched, with seedling lines attached to them. The lines are situated 1 [m] above the ocean bottom. The seedling lines are made out of nylon, with giant kelp secured to it. Figure 5.2 shows in detail what the prototype looks like. The dimensions are 75 [m] x 40 [m]. The exact coordinates are given in table 5.1.

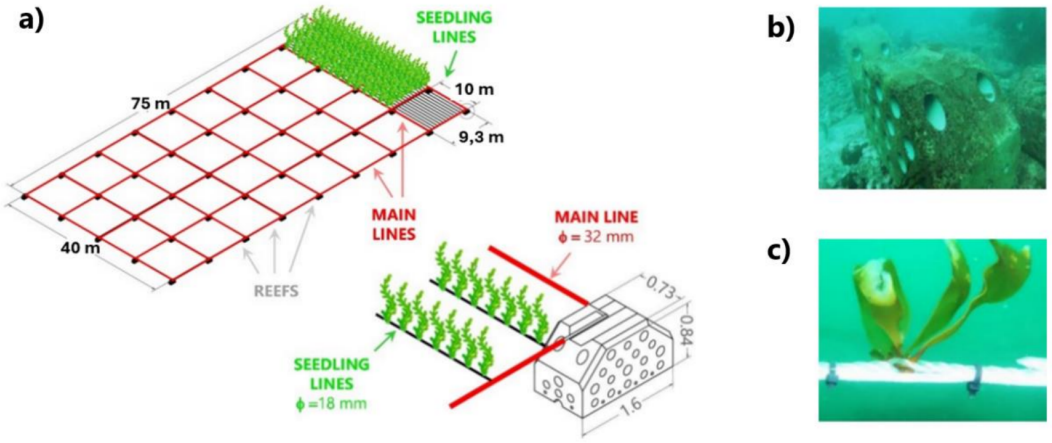


Figure 5.2: Prototype kelp structure. (a) Overall structure, including the main and seedling / secondary lines (b) Artificial reefs made out of concrete (c) Seedling connected to the secondary line

The Giant Kelp forest is still being planted as of now, which means the size is relatively small. The diameter is now estimated at 30 [mm]. When attaching the kelp to the rope, the fishermen use a distance the size of their fist between different stems. A maximum density of 10 $[u/m^2]$ is then possible to achieve. It is estimated that 60% of the kelp in the ocean will die or get loose from the rope. Thus only 4 $[u/m^2]$ will survive. The height of the kelp forrest (h_v) is the same height as the water depth (h) minus 1 [m] (Pontificia Universidad Católica de Valparaíso, 2023).

Corner	Latitude (S)	Longitude (W)
Top left	32°38'39.53"S	71°26'37.01"W
Top right	32°38'39.51"S	71°26'34.13"W
Bottom left	32°38'40.83"S	71°26'36.88"W
Bottom right	32°38'40.80"S	71°26'33.98"W

Table 5.1: Coordinates of the kelp forest (Pontificia Universidad Católica de Valparaíso, 2023).

5.3. Experiments with Kelp

It is important to understand what has previously been done to investigate the effect of kelp on attenuating waves. This section dives further into the numerical studies that have already been in this project and which roll this project will now fullfill.

5.3.1. Numerical Modelling

The numerical models are used to define the density and volume of the kelp forest to effectively dissipate energy. Because these specific algae species are long and flexible, the stiffness is reduced and the buoyancy is high. The plants cannot be considered as vertical cylinders and a simple drag force model, commonly used for vegetated shore modelization, is not valid. A more complex set of models is needed to describe the required forces.

The main variables that describe the kelp forest are the density, height and diameter of the kelp. Each of these variables has a high inaccuracy, as the individual kelp is simplified to reduce computational time. For the modelling, three programs are used: ANSYS Fluent describes the fluid-algae

interaction for individual algae and algae as a whole, Aquasim the fluid structure (finite element model for the design) and XBeach the hydro- and morphodynamic model. The interaction between the models is shown in figure 5.3. The drag coefficients of ANSYS Fluent are used in Aquasim for the displacements and internal stresses of the elements, but also in XBeach and SWAN to simulate the frictional forces. To thus far, in this project SWAN has only been used as a wave forecast in order to predict when divers can plant kelp in the prototype forest in Maitencillo. It is however also a great tool to model wave attenuation by the prototype kelp forest.

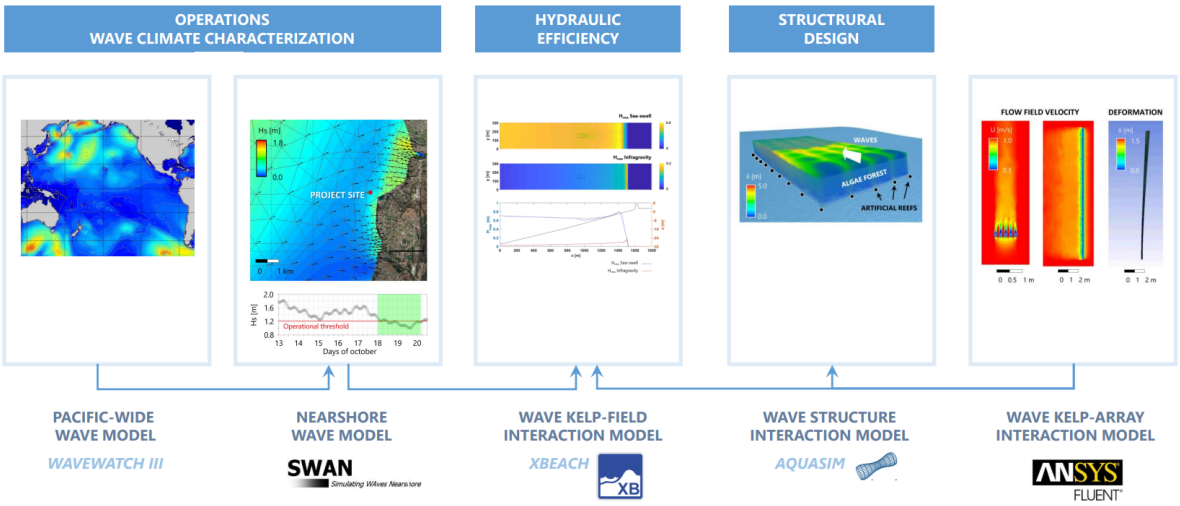


Figure 5.3: Structure of models.

SWAN

SWAN (Simulating WAves Nearshore) is a numerical model that determines the wave energy flux and is used to evaluate the effect of vegetation on wave conditions. In case of no energy dissipation and stationary conditions, the following equation is valid:

$$\frac{\partial F}{\partial x} = 0; \frac{\partial}{\partial x}[E \cdot C_g] = 0 \tag{5.1}$$

The wave energy is described by a two-dimensional energy density spectrum by the frequency and direction. SWAN can describe the hydrodynamics in one and two dimensions. It has an option to include wave dissipation due to vegetation where the cylinder approach is used. This means that the vegetation is modelled as cylinders which cause drag resistance. This gives the mean rate of energy dissipation by vegetation per unit horizontal area, given by the equation of Mendez and Losada (2004):

$$\epsilon_v = \frac{1}{2\sqrt{\pi}} \rho C_D b_v N (\frac{kg}{2\sigma})^3 (\frac{\sinh^3 k\alpha h_v + 3 \sinh k\alpha h_v}{3k \cosh^3 kh_v}) H_{rms}^3 \tag{5.2}$$

where:
- C_D is the Drag Coefficient [-]
- b_v is the Stem Width [m]
- N is the Density of the vegetation [stems/m²]
- h is the Height of the vegetation [m]

6

Local awareness on coastal erosion

6.1. Importance of creating awareness

In coastal towns such as Quintero and Maitencillo, the preservation of beaches is very beneficial to its local residents for multiple reasons (recreation, income, tourism). In these situations, authorities (municipality, enviromental organisations etc.) should be encouraged to take action to increase local awareness and understanding that support the effective management of the coastal environment. It's crucial for the residents of such towns to be aware of the risks of coastal erosion, allowing them to adapt their behavior to help mitigate it (Tourlioti, Portman, Tzoraki, & Pantelakis, 2021).

Research on past policies suggests that increasing awareness can enhance the effectiveness of regulations aimed at preventing coastal erosion. In turn, this may reduce the need for authorities to invest heavily in compliance and enforcement efforts (Portman, 2006). Other studies on public perception have emphasized the need for coastal management initiatives to inform and educate the public, especially beach users, about the issues of coastal erosion (Semeoshenkova & Newton, 2015). Research of Dribek and Voltaire (2017) noted that effective public awareness offers multiple advantages for the decision-making process, as it can help anticipate conflicts, increase acceptance, trust, and the level of funding during financial challenges.

All these previous studies suggest that local awareness plays an important role in the effective combat of coastal erosion. By informing and engaging local communities, residents become active participants in protecting their environment. A well-informed public is more likely to support and comply with regulations, which are imposed on them by authorities. Ultimately, empowering residents with educated knowledge should hopefully contribute to the sustainable preservation of Chile's coastal regions.

6.2. Local awareness assessment

This research is aimed to assess the social support of the kelp forest solution for preventing coastal erosion. As has been explained, the local awareness at the two defined beaches will therefore be explored. First, it's important to clarify the type of awareness being discussed. The first aspect involves awareness about the existence of coastal erosion and knowledge of its impact. The second crucial point is awareness about the potential solution of a kelp forest that could mitigate coastal erosion. Moreover, the insights that will be gained are used to make recommendations for achieving the highest potential of local support. Therefore, a survey has been conducted in which the local awareness is assessed through different questions regarding coastal erosion and the kelp forest project.

The survey questions which can be found in Appendix I, are targeted to gain understandings on whether people acknowledge the changing surroundings and different dynamics due to coastal erosion. It is aimed to illustrate their perceptions on coastal erosion and its consequences. Additionally, the kelp forest application is also presented in the survey. Here, the goal is to find out whether local stakeholders are aware of the working of kelp as well as the initiative of the project team. Consequently, it can be explored how the local stakeholders perceive the potential benefits as well as possible unwanted results of farming kelp forests at the local beaches.

Thus, the survey is used to gain these insights and understandings of local stakeholders and their perception of awareness. The survey respondents were divided into three different stakeholder groups,

which all received a different survey with mostly the same questions but with a slight alteration. Furthermore, the three stakeholder groups in this research are defined as; local residents, fishermen and local businesses. This distinction has been made to explore whether different connections with the beach areas would lead to different levels of awareness and willingness to take action. The survey was handed out to different people who fitted these descriptions and these respondents filled in the survey with pen and paper. Here, the survey consisted of different statements regarding the coastal erosion and the kelp forest in the area of Maitencillo. The respondents were given a scale from totally agree, agree, neutral, disagree and totally disagree regarding the statements. Afterwards, the data has been collected and analysed.

Not only did the survey consist of statements which the respondents had to rank, the survey also included open questions. Moreover, these open questions were asked to gain a deeper insight of the perception of the respondents on coastal erosion in their personal experiences. The goal is to create an image of what people have experienced in their living experience or working situation regarding coastal erosion. Also, the open questions are used to explore whether the respondents see certain benefits or threats in respect to the expansion of the ongoing kelp forest project. Finally, these answers can be used to explore the support of the local stakeholders on the kelp forest project rather than only their knowledge and awareness towards it.

Figure 6.1: Respondents filling in surveys

6.3. Statistical analysis of survey results

After the surveys had been handed out, the results can statistically be analysed with SPSS. Here, the analysis is aimed to explore the perception of awareness on the described local stakeholders. Not only is the aim to measure the level of awareness, it is also intended to explore different relations between characteristics and awareness such as age and town of residence. Consequently, these analyses can be used to eventually make conclusions on which factors might affect one's perception of awareness on the coastal erosion and its applications.

In order to gain this knowledge, different analyses are performed. Firstly, the demographics are analysed of the respondents of the survey. Afterwards,a principal component analysis is performed to explore whether different statements of the survey explained a certain distinct attitude. Thus, it is assessed whether, for example, an attitude of awareness regarding a more specific application of coastal erosion could be explained by a set of statements. The goal is here to identify which statements

fit a specific attitude and therefore explain a certain perception. Furthermore, it can be analysed whether respondents matched these attitudes and to what extent. Finally, the influence of different aspects on the level of awareness of coastal erosion is considered.

After these analyses, insights can be gained on what the current local awareness is of the stakeholders and what influences these perceptions. Consequently, recommendations can be made on potentially raising more awareness.

6.3.1. Demographics of respondents

The demographics of the respondents will be analysed to see which variation there is amongst respondents. Moreover, these demographics are used in further analyses.

Age

The age of all the respondents has been asked to explore whether age plays a role in the awareness of coastal erosion and the kelp forest project. Here, people of an age of 18 or higher were asked to fill in the survey. Eventually, 66 respondents filled in the survey where the youngest was 19 and the oldest was 72 years old. Moreover, the average age is 46 and Figure 6.2 shows the division of different ages.

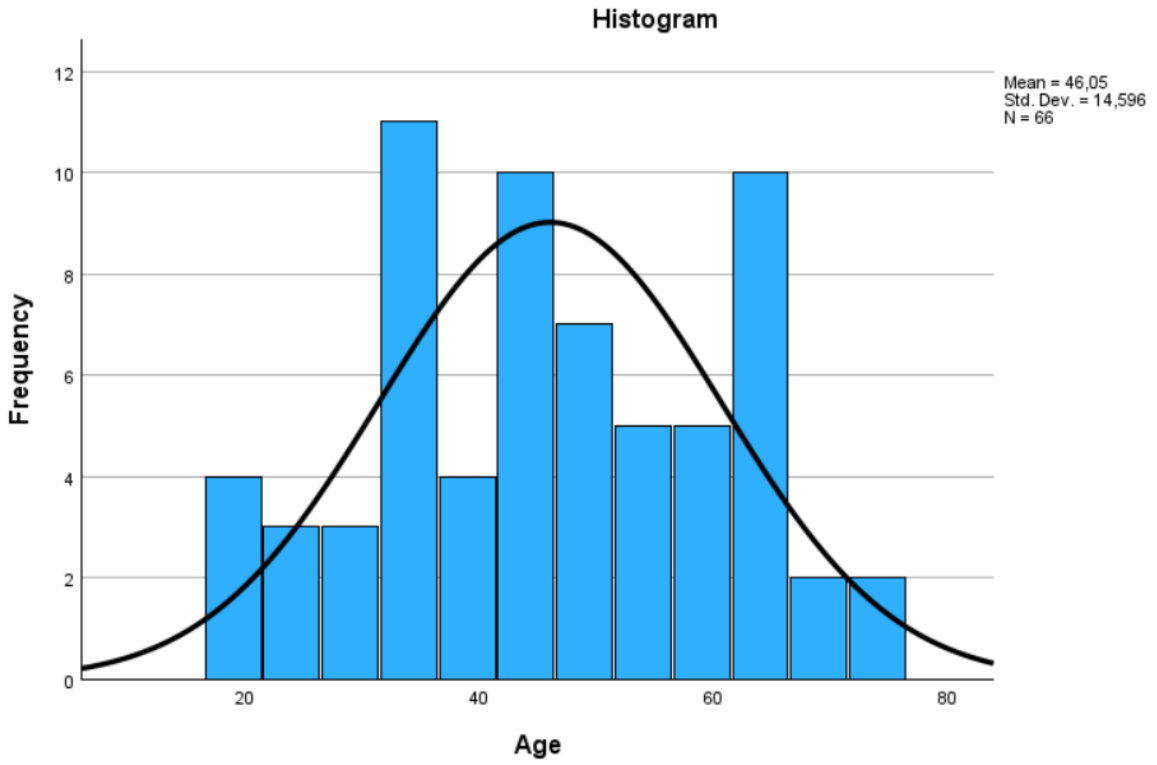


Figure 6.2: Age distribution respondents

Town of residence

As the research has the scope of the two different towns of Maitencillo and Quintero, only residents of these towns have been asked to fill in the survey. Eventually 28 residents of Maitencillo and 38 residents of Quintero have filled in the surveys. Thus, it can be noted that more residents of Quintero filled in the survey. However, as explained in this report, Quintero has more residents than Maitencillo, especially in the off season. Therefore, this difference has been considered as neglectable.

Gender

Furthermore, the gender of each respondent was noted as well. Here, the respondents had the options of female, male or other in order to explore differences in gender. Finally, the survey had been filled in by 19 female respondents and 47 male respondents. Also in this case this difference has been considered as neglectable in further analyses.

Target groups
For the awareness assessment, as explained, three different groups have been distinguished as stakeholders. Thus, the survey was divided between local residents, local businesses such as restaurants and stores close to the shore and finally fishermen. Eventually, the survey was filled in by 30 local residents, 20 fishermen and 16 employees of local businesses.

6.3.2. Statements
The statements which were given to the respondents can be described as latent variables since they explain a certain behavior which is not measurable directly. The statements had to be scored according to the described scale from completely disagree to completely agree, these scores have been transformed into a scale from 1 to 5 accordingly. All statements can be found in the Figure 6.3 below.

S1	I am aware of coastal erosion occurring along the Chilean coasts.
S2	I believe coastal erosion poses a danger to Chilean beaches.
S3	I have noticed changes in the beaches over the last few years, such as a reduction in beach length or a decrease in marine species diversity.
S4	If yes, I believe these issues should be tackled.
S5	I am familiar with the concept of kelp farming as a method to prevent coastal erosion.
S6	I am interested in learning more about kelp farming or participating in activities related to it.
S7	I feel that I could get involved in local initiatives if I wanted to.
S8	I am concerned about the long-term effects of coastal erosion on my community.
S9	I am aware of the ongoing kelp forest project at the Caleta beach, led by the research team of the universities in Valparaíso.
S10	I am aware that the underwater kelp forest at Papagallo beach has been completely removed in the last 80 years.

Figure 6.3: Statements survey

6.3.3. Principal component analysis
Furthermore, to explore whether different statements could be combined to create components which describe a certain attitude, the principal component analysis(PCA) has been performed. Furthermore, the principal component analysis has been used since this analysis makes sure that the statements can be combined to describe underlying pattern. The components which will be formed as a result of the PCA, represent a set of statements that correlate and explain a shared attitude. Furthemore, these components are interpreted by how the statements' factor scores load towards the components.

For the principal component analysis, the rotation method which has been used is the Varimax with Kaiser Normalization. The rotation generally shows a more clear image of the components and make the analysis easier to interpret. Here, the coefficients of the factor scores below 0,5 have been suppressed in order to incorporate the statements with the biggest correlation with the components. Consequently, two components have been created which involve different statements which all load at least 0.5 towards the components. The elaborate results of the PCA can be found in Appendix H.1

Component 1
Firstly, component 1 involves the following statements: S1,S2,S3,S4 and S8. Considering the content of these statements, this component will be labeled as Awareness of coastal erosion threats. Thus, this component and its statement will describe the attitude of the stakeholders whether they are aware of the threats of coastal erosion in Chile and more specifically in their surroundings.

Component 2
Secondly, component 2 involves the remaining statements: S5,S6,S7,S9 and S10. Also, here the consideration was made with which specific attitude these statements can be labeled. Moreover, it was considered that these statements mostly explain the openness and awareness towards interventions regarding the mitigation of coastal erosion. Mostly this is described by the kelp forest project in Maitencillo but also by the willingness to be involved in local initiatives. Consequently, component 2 will be labeled as Awareness of possible interventions against coastal erosion.

Cronbach's reliability test
In order to make sure that the components which have been set up explain the data well, Cronbach's reliability test is performed. For this reliability test, the value of 0,7 is used as a minimal requirement to be considered reliable. The result of this reliability test showed that Cronbach's Alpha for component 1 is 0,921 and 0,861 for component 2. Therefore, the reliability test for these components is passed, and this means that the components are reliable as a scale.

Sum scores
Since the reliability test has been performed and the components can be considered as fitting, the sum scores are conducted. Here, the decision has been made to use sum scores where all the scores of the individual statements are combined. These combined scores are divided by the amount of statements and are thus average sum scores. Therefore, these sum scores show the average amount of awareness that each respondent has for both of the components; threats and interventions. Finally, these sum scores can be used to create an understanding of which levels of awareness the respondents have on the coastal erosion threats and possible interventions.

6.3.4. Local awareness analysis of local stakeholders
In order to find out to what extent the stakeholders are aware of coastal erosion and which demographic aspects influence this level of awareness, a final analysis is conducted. Firstly, the local awareness is explored by analysing the sum scores of the created components. These results will show to what level the local stakeholders are aware of the threats of coastal erosion as well as their awareness on possible interventions and solutions. Afterwards, a further analysis will show whether different demographic aspects influence the level of awareness of the local stakeholders.From these insights, further recommendations can be suggested to create more awareness on coastal erosion at the Chilean coasts.

Overall levels of awareness
For the awareness perception of the respondents, the graphs in Appendix H.2.1 show to what extent each respondents score on the awareness of the threats of coastal erosion and the awareness of possible interventions for coastal erosion. From these results, it can firstly be noted that the overall awareness on the threats of coastal erosion of the local stakeholders in Maitencillo and Quintero can be considered high. The average amount of awareness is a score of 4,51 out of 5, where 5 can be considered as totally aware. Furthermore, the awareness of these local stakeholders on the possible interventions and solutions for coastal erosion can also be considered quite high. The average perception of awareness on this aspect is 3,97 out of 5, accordingly to the same scale. Therefore, it can be considered that the overall level of awareness of the threats of coastal erosion is high of local stakeholders and the awareness of possible interventions relatively high but lower. Consequently, it can be noted that local stakeholders are aware of the issue of coastal erosion but can still learn more about which interventions can and should be taken to battle coastal erosion issues. Nevertheless, there are still local stakeholders that are not fully aware of the issue of coastal erosion or even aware of it at all. The same graph shows that 6 percent of the stakeholders is not (fully) aware of the threats of coastal erosion and that 20 percent is not aware of the possible interventions. Since the sample size is not that big, it is harder to conclude whether the overall average awareness is indeed as high as perceived through the surveys.

Influence of age

For exploring the influence of age on awareness of coastal erosion, three age groups have been set up. The age groups have been divided in the ages of 18-30, 31-60 and 60+. Here, it could be noted that the most respondents were present in this middle aged group. Additionally, the age of the respondents is regarded in its influence to see whether a certain age group is relatively less or more aware of the coastal erosion. As can be seen in the tables in Appendix H.2.2 the awareness on the threats of coastal erosion is on average relatively the same, with a difference of not even 0.1 on the average scale. However, it can be noted that in the awareness of the possible interventions, the oldest age group scores the highest and the youngest age group the lowest. Nevertheless, it most also be noted again that the sample size is relatively small when the age groups are divided and that only averages are considered.

Influence of town of residence

As has been explained, the difference between the two towns Maitencillo and Quintero is that the kelp forest project is actually being installed in Maitencillo and not in Quintero yet. Therefore, it will be explored whether the local stakeholders of Maitencillo are more aware of coastal erosion and its consequences than the local stakeholders of Quintero. The average scores shown in Appendix H.2.3 of the threats component show that there is a slightly higher average in Maitencillo than in Quintero. However, the interventions component has a slightly higher average in Quintero than in Maitencillo. Thus, this was not initially expected but with this data it is difficult to draw firm conclusions on whether this is generally the case. Follow up research could be conducted to see whether the installment of a kelp forest project in an area does directly lead to more awareness of coastal erosion on local stakeholders. Here it could be analysed whether background knowledge is crucial for this awareness rather than the project merely being present within the local area.

Influence of stakeholder category groups

Lastly, it is considered whether the different local stakeholder groups have differing averages of awareness. Thus it is explored whether for example residents have a different average of awareness than fishermen. Firstly the tables in Appendix H.2.4 show that for the threats of coastal erosion, the fishermen score the highest level of awareness, closely followed by the local residents and the level of the local businesses is on average a bit lower. For the interventions awareness level, the local residents and the local businesses score exactly the same average and the fishermen score on average more than 0,5 higher. Therefore, it can be considered that fishermen generally have the highest awareness compared to local residents and local businesses. This were to be expected since the fishermen are closely involved with the aquaculture and therefore most likely experience the coastal erosion the most. Consequently, follow up research could be conducted on how different characteristics in each stakeholder category such as educational levels influence the awareness of each group. This could potentially sketch a more complete image on why certain stakeholder groups have different levels of awareness through different aspects.

6.3.5. Key findings from open questions surveys

The surveys also included three open-ended questions to gain deeper insights into personal experiences with coastal erosion. The following three questions were asked:

- How has coastal erosion impacted your personal experience with the beach or local environment? Do you think it will affect for example your property or community in the future?
- Do you see any disadvantages of introducing algae farming to your local beaches? Think of how more kelp could change the beach surroundings and your personal experiences.
- How do you think that kelp farming could influence your business (for fishermen and local businesses) / living situation (for local residents)?

These questions provided valuable perspectives, with several key findings highlighted below:

- “Playa Caleta is disappearing. For the years that I have been living there, the sea has been consumed in a short time.” (Fisherman)
- ”When I was a kid I came to the Caleta beach and there was a full forest of kelp underwater, which also covered a large part of the beach. So, I don’t see any disadvantages of an artificial kelp forest.” (Fisherman)

- ”I think the kelp forest would have a positive influence since there would be more seafood and fish.” (Fisherman)
- ”The length of the beach and constructions have been reduced in the last few years. It affects my personal experience since the entire beach area has been reduced in size, affecting also the recreational sporting in the region.” (Local resident)
- ”I would have to know more about the kelp project to say something about the disadvantages, but I’m curious.” (Local resident)
- ”I think that for swimming it will be more inconvenient with the giant kelp being in water.” (Local resident)
- ”I’ve experienced that a reduced surface for swimmers and surfers is left and that the coastal infrastructure is exposed. Without the beach, there are less tourists. Also, this results in an increase of stones and rocks that are uncovered.” (Local business)
- ”The beach is an important selling point for my restaurant, so I would like it to stay beautiful that way.” (Local business)

6.4. Expert interviews

Not only have surveys been used to gain a better understanding of the local awareness, several interviews with key stakeholders have been conducted as well. The elaborated version of the interviews can be found in Appendix C-I. A few insights have been gained from these interviews on the local awareness of coastal erosion as well as the consequences of coastal erosion on the chosen areas.

The first interview was conducted was the *Interview with Anna Cabagal* (2024), an employee in the environmental department of the municipality of Puchuncaví. She explained that the municipality is well aware of the coastal erosion issues, having witnessed the degradation of Playa Caleta firsthand. While residents also notice the shrinking beaches, many are not fully aware of the underlying causes. Although Cabagal acknowledges these challenges, she mentioned that the municipality is not currently planning to raise awareness about coastal erosion. Instead, their primary focus is encouraging locals to clean up the beaches and take care of the environment. Despite this, the municipality chose to support the kelp forest project, recognizing both the importance of addressing coastal erosion and the need to restore the beaches for the benefit of the local economy. It seems that some members of the municipality understand the problem well, but have yet to take steps to educate their residents about it.

An interview was also conducted with the mayor of Puchuncaví, Marcos Morales Ureta. The *Interview with Marcos Morales Ureta* (2024) confirmed what Anna Cabagal had already shared. He also mentioned that there are currently no substantial plans to address coastal erosion, and that residents are not fully aware of the severity of the issue. He emphasized that the municipality’s focus is primarily on beach clean-up efforts, including organizing various cleaning events and educating schoolchildren on the importance of maintaining the environment.

The *Interview with Maria Martinez* (2024), an employee in the environmental department of the municipality of Quintero, revealed a different perspective within the municipality. Martinez explained that both the municipality and the residents don’t perceive coastal erosion as a significant issue. Instead, their main environmental concern is air quality, which is heavily impacted by the large polluting industries in the Quintero Bay. Due to this focus, coastal erosion is not seen as a priority, and most members of the municipality show no interest in collaborating with the kelp forest research team.

The *Interview with Ricardo Silva and Carlos Vega* (2024), members of the Maitencillo Fishermen’s Association (Sindicato de Pescadores) provided some unexpected insights. Ricardo Silva, the association’s president, expressed disbelief in climate change and, as a result, did not acknowledge coastal erosion as a significant issue. He attributed the degradation of the beaches solely to construction projects near the shore. Milton Magnere mentioned that not all members of the associations share the same ideas. However, this does suggest that even someone in a key position, like Silva, lacks awareness of the underlying causes of coastal erosion and is not well-educated. Interestingly, he still supported the kelp forest project, but solely because he remembered that a natural kelp forest once existed at Caleta, which attracted more shellfish to the area.

The *Interview with Fishermen’s Federation of Quintero* (2024) was also conducted with three members, who expressed a strong awareness of the coastal erosion issues, having witnessed the changes firsthand at Papagallo beach. They believed that everyone working or living along the coast was highly

aware of these problems, but they felt that the common residents were far less informed. Nevertheless, the majority of their association had voted against participating in the kelp forest project, primarily because they wanted compensation for their involvement.

Lastly, the *Interview with GNL Quintero* (2024), a major company operating in Quintero Bay that handles the unloading, storage, and regasification of liquefied natural gas. The interviewees were all highly educated and well-informed about coastal erosion, including its causes and consequences. When asked about their involvement in raising environmental awareness among local residents, they explained that this was not a primary focus for the company. Instead, they prioritized (what they thought) more pressing issues, such as air quality and access to potable water.

Figure 6.4: Interview with the mayor of Puchuncaví

6.5. Current initiatives for creating awareness

Since the assessment of the current level of local awareness has been done, ongoing initiatives will be explored. The current initiatives for creating awareness are distinguished between those of the local authorities and those of the kelp forest project team. This information has been gathered through the presented interviews and site visits to different events. Currently, most initiatives for coastal erosion awareness and the kelp forest project are taken in Maitencillo and the municipality of Puchuncaví, rather than in other municipalities such as Quintero. However, the survey has not shown clear indications of the awareness being significantly higher within Maitencillo than in Quintero.

6.5.1. Initiatives by local authorities

Beach cleaning initiatives

The interview with Cabagal explained that local initiatives by authorities are mainly focused on making local residents more aware of the importance of sustainability and clean beaches (*Interview with Anna Cabagal*, 2024). Here, she states that the current initiatives focus on making schoolchildren more environmentally aware. As for now, there is no specific focus on coastal erosion within these initiatives. The main message of the current initiatives regarding coastal areas is on educating children on the impact of garbage on these areas. Therefore, different beach cleaning events are organised where local authorities and residents, as well as children, gather to clean coastal areas in and outside of the water. An example of one of these events is the event of 25-09-2024 where a beach at Quintero was cleaned. The event was guided by Reciclador, an organisation focused on removing and recycling garbage. Multiple stakeholders were at the event with a stand, trying to share their knowledge with people who attended the event. Stakeholders present included the Ministry of Environment, the marine army (Armada), and the municipalities of Puchuncaví and Quintero.

(a) (b)

Figure 6.5: (a) Cleaning the beaches (b) All participants of the event

6.5.2. Initiatives of the kelp forest project team

Awareness for local authorities

Currently, there are different initiatives executed on coastal erosion, but mainly by the kelp forest project team themselves. Firstly, Magnere states that initially there was a conference meeting with different local authorities where the project was presented and different questions could be answered (*Interview with Milton Magnere*, 2024). As part of the event, they also organized a small market, with each stand providing relevant information. Magnere noted that the event didn't attract many locals, but he also admitted that this was actually not the intention. This type of initiative was used to raise awareness among stakeholders but also to seek for (financial) collaborations within the project. The project is now still only funded by the central government and more funding is needed to scale-up the project. Therefore, the kelp forest team tries to attend different local events to raise awareness on different stakeholders and thus to aim for these kinds of collaborations.

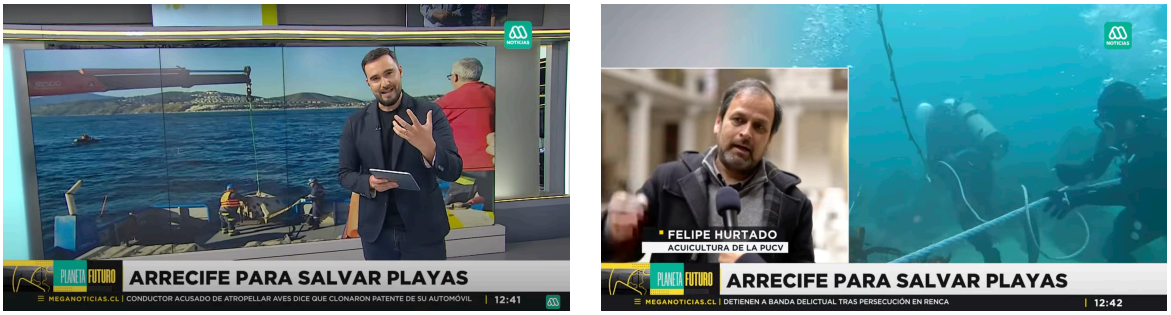
Awareness at primary schools

Not only is the project aimed to raise awareness for potential collaborations, Magnere argues that the project is also used to educate children on coastal erosion. He is pursuing this initiative as part of an agreement with the municipality of Puchuncaví; in return for their support, the research team committed to teaching at several schools to raise awareness about the algae project and broader environmental issues. (*Interview with Milton Magnere*, 2024). An example is the presentation of Magnere on 06-09-2024 at a primary school (Escuela Maitencillo) where the topic of coastal erosion was discussed. Additionally, the presentation showed the children the consequences of coastal erosion and the potential of the kelp forest project.

Figure 6.6: Presentation of Magnere at primary school

Awareness on national television

The research team is also working to raise national awareness about coastal erosion. Their efforts led to an appearance on the evening news on 2 October, featured on Meganoticias, one of Chile's most-watched news channels (Meganoticias, 2024). They reach around 60.8% of the population (*MEGA ARRASÓ CON TODO EN JULIO | Megamedia*, n.d.). During the segment, they had nearly two minutes to explain the coastal erosion issues and how their project offers a potential solution. The project team was pleased with the news coverage, hoping it would help them reach and inform a wide audience.



(a) (b)

Figure 6.7: (a) News item on Meganoticias (b) Felipe Hurtado speaking, head of kelp forest research team

6.6. Potential strategies for raising awareness

As for now, besides the efforts of the kelp forest project team there are not many efforts to raise awareness among local stakeholders on coastal erosion. Therefore, it will be explored which new initiatives can be set up to raise awareness on the cause of coastal erosion, its results and threats and which possible interventions can be taken to mitigate it such as the kelp forest project. Different distinctions will be made in terms of observed characteristics through the surveys and the expert interviews. Here, each characteristic has its own specific strategy to increase awareness, based on where the current awareness is lacking for that specific group.

6.6.1. Initiatives for youth

Children can be considered as the future for change, educating children will probably result into possibilities for the future. Therefore, making sure that the awareness of children is raised in environmental issues such as coastal erosion would be beneficial for future initiatives. Here, the distinction for children is made since the approach for reaching small children and young adults could differ from the

way to reach older generations. The current awareness is lacking in terms of educational efforts for the Chilean youth in coastal areas. The *Interview with Anna Cabagal* (2024) showed that the children in the municipality of Puchuncaví are now mostly educated on environmental awareness overall rather than on the specific applications of coastal erosion. Therefore, there are opportunities to raise awareness for the children in Chilean coastal areas.

Educational activities

Currently, the kelp forest project team gives small lectures to some local primary schools to raise their environmental awareness on coastal erosion. Research conducted by Bergman (2015) on giving children environmental education showed that there had been an increase in the appreciation and intention for environmental learning. Moreover, the same research on different school groups showed that more than a third of the students mostly enjoyed environmental education by having a chance to go outside and learn. Additionally, Öllerer (2015) argues that since environmental issues are pressing, the involvement of this matter in educational curricula are often lacking. Therefore, Öllerer (2015) stresses that environmental education should be fully integrated in educational practices in order to change behavior and environmental awareness, rather than treating it as a scientific discipline. Nevertheless, Andersson and Öhman (2015) emphasize that knowledge sharing does not always directly lead to a change in behavior and show that outdoor experiences have a higher influence in changing attitudes and values. Thus it could be recommended to create outdoor experiences where children experience the changing environments due to coastal erosion. Furthermore, site trips to for example the kelp forest could make sure that children see that actions are being taken to prevent these effects.

Online educating activities

Besides physical experiences with coastal erosion, it could also be beneficial to educate children on coastal erosion and environmental awareness through online platforms. The online world seems to be evolving gradually and children are using online platforms such as social media on a daily basis. Additionally, the study of Hajj-Hassan, Chaker, and Cederqvist (2024) shows that digital tools have positive influence in terms of educating students on environmental knowledge. One of the examples mentioned in their research is the usage of VR to create experiences where students perceive physical situations which makes sure that a sense of sensory experience is created, promoting environmental education. As not all children will live close to coasts and it will be harder to show them the consequences in real life, these virtual experiences could be used to educate them as well. Another possible online initiative would be to create educating as well as amusing social media accounts to educate children online. Here, children could be educated the same way as grown ups would by watching the news articles, but then in a way that catches their attention.

6.6.2. Initiatives for middle aged adults

Not only is it important to educate children, it is also crucial to educate the middle aged adults. The *Interview with Fishermen's Federation of Quintero* (2024) showed that local residents have the tendency to be hesitant to local projects. Furthermore, the reasoning behind this doubt is the history of local projects which the municipality had invested in, but no efforts were taken into realizing the project. Therefore the interviewed residents expressed the feeling that their money was taken away without any operations getting started. Thus, it is very important to create an open communication community where the residents actually get to experience what is done with the money in the project. In order to achieve this understanding the initiatives can be considered in twofold, firstly to show why coastal erosion is an important matter to take action for and secondly how these projects such as the kelp forest are needed to battle coastal erosion. With these efforts, coastal erosion awareness can be created as well as a proactive attitude where local stakeholders see that actions should be taken.

Creating awareness of severance of the issue

Currently, the survey showed that there is a sense of awareness present on the coastal erosion threats and ways to create intervention. However, the *Interview with Anna Cabagal* (2024) and *Interview with GNL Quintero* (2024) showed that most local residents do not really regard the importance of mitigating the issues. This mostly was the result of other pressing environmental issues within the local communities, as for example the mentioned air pollution or the cleaning of the local beaches. Therefore, not many efforts are taken to make people aware of the fact that action should be taken against coastal

erosion as well. Another insight of the *Interview with Anna Cabagal* (2024) showed that people need to see the changes that are made in order to believe that something is effective and needed. Here, the example of building an underwater wall was used and it was stated that people would not want to invest in these measures since the working would not be directly visible.

Overall, it can be considered that to make this age group aware of the actual importance of the coastal erosion issues and to show them that projects are used to combat this, initiatives could still be taken. Examples to create this awareness could be local community meetings where locals will be educated on why coastal erosion should also be considered as a priority. Here, the local stakeholders can participate in the town meetings on coastal erosion awareness and the baseline can be set for community involvement in local initiatives (Almeida, González, Flores, Curry, & Padilla, 2023). Experts such as the kelp forest project team could inform the local stakeholders on the project and show them the importance of the matter. Moreover, these town meetings could be combined with other topics that are currently seen as pressing to make sure that more people will attend that do not yet see the importance of coastal erosion yet.

Also, publicity will be an important tool to make people more aware of the ongoing issues and initiatives. Through media channels such as the newspaper and television, more people can be reached. The news broadcast of the kelp forest project is a good example of how many people can be reached. Media plays an important role in the creation of people's perceptions on environmental issues (Jharotia, 2018) and therefore should be taken into account when creating awareness.

Creating involvement in ongoing projects

Like stated before, merely spreading information will not always lead into a proactive attitude toward making changes and being involved in projects. Therefore, it is crucial to make sure that a sense of involvement and being included is experienced by the local stakeholders so that they see where the money and effort goes into. Stakeholder management is mostly focused on stakeholders with the ability to control the project, while the stakeholders such as the local community is rather unexplored (Di Maddaloni & Davis, 2017). However, the research of Di Maddaloni and Davis states that actively seeking for the opinion of the local community in the initiation of a project and to let them monitor the process, will in the end make sure that the project has a better performance.

This sense of involvement can be achieved by setting up co creation meetings, were the local communities can express their concerns on the planned project operations. Additionally, these meetings can result into the sense of being heard and involved in the project. Also this inclusion can be reached through creating focus groups with local residents, fishermen and businesses. The research of Reed (2008) notes that people are more likely to actually engage in projects when they feel like they have the chance to express their opinions and concerns. In this case, this could be beneficial for the project team as well since the local stakeholders such as the fishermen and residents have many knowledge of the project area and the challenges that come with it.

6.6.3. Initiatives for elderly

Finally there is the age group of elderly which also needs to be considered in enhancing awareness and pro-activeness in coastal erosion issues. Moreover, the survey showed that older people have experienced coastal erosion in their own personal living experiences by seeing the beaches disappear. Therefore, they will have some awareness on the disappearing of the beaches, but the *Interview with Ricardo Silva and Carlos Vega* (2024) showed that this does not always result in them acknowledging coastal erosion. Here, it is important to note that older people are harder to reach through media channels and also to make them come to local community meetings. However, the older people probably have lived the longest time in the areas and therefore know the coastal areas and how they have changed, the most. The importance of including environmental inclusion with older people has been proven beneficial (Pillemer et al., 2016). Therefore, to reach the elderly it is crucial to achieve more personal attention. The article of Pillemer et al. (2016) elaborates on the Retirees in Service to the Environment (RISE) program where a program is designed to actively involve older people through knowledge and involve them initiatives. In this case, a sort like program could be used to gain the insight of the elder by personal outreach such as home visits and elderly houses to raise awareness and create involvement.

7
Stakeholder analysis

This chapter includes a stakeholder analysis of the involved stakeholders of the coastal erosion issue in Chile, specifically for the experimental kelp forest solution that has been initiated. Thus, it merely addresses the interests and power of the stakeholders (possibly) involved in the kelp forest project. The analysis was conducted in collaboration with the kelp forest research team, as both studies share a common goal: investigating the feasibility of utilizing kelp forests as a solution for coastal erosion. Therefore, an analysis is conducted on how various stakeholders perceive the implementation of a kelp forest as a potential solution for mitigating coastal erosion. These insights can later be used to develop a roadmap for scaling up the kelp project and to identify potential collaborators interested in working with the research team. Firstly, different stakeholders on a local, regional, and national scale are identified for the described scope. After, the formal power, interests, and attitudes of these stakeholders will be conceptualized. Finally, the gathered insights are used to create a relationship diagram of all key stakeholders, highlighting the necessary collaborations for establishing and potentially scaling up the kelp forest project.

7.1. Stakeholder identification

7.1.1. Local stakeholders:

Fishermen's association (Sindicato de Pescadores)
The fishermen are important stakeholders in Quintero as well as in Maitencillo to ensure the success of the implementation of the kelp project. This is because the Sindicato (fishermen's association) owns the shoreline and holds the permit granted by the Chilean Armed Forces to conduct aquaculture activities. As a result, they are the key stakeholders who need to be convinced in the initial stages of introducing a kelp forest project. This way, the project team can proceed with developing the kelp forest, while the Sindicato retains responsibility and accountability to the Navy. (*Interview with Milton Magnere*, 2024).

In the Maitencillo area, there used to be a natural kelp forest many years ago (*Interview with Milton Magnere*, 2024). During the surveys, they mentioned that this makes it easier for them to accept the solution of growing a kelp forest to mitigate coastal erosion because they have seen with their own eyes that this reduces the wave strength. Also, from the interview with (*Interview with Ricardo Silva and Carlos Vega*, 2024), it became clear that the fishermen's association of Maitencillo voted in favour for the implementation of the kelp forest to mitigate coastal erosion.

In Quintero, the fishermen's association voted against the plan for the kelp forest. According to Patricio Tagle, this is because the fishermen have had some bad experiences in the past and now insist to get paid (*Interview with Fishermen's Federation of Quintero*, 2024). The surveys did show that the fishermen are aware of the coastal erosion problems. Unfortunately, feelings of distrust have overshadowed the willingness to solve this problem.

Local residents
As explained in chapter 6, local residents are key stakeholders because they can become active participants in protecting the environment. Also, from the surveys, it became clear that they care about

the beach and the protection of it. In both Quintero and Maitencillo, some houses were constructed too close to the beach, leading to their collapse as stronger waves eroded the shoreline. The surveys also revealed significant variation in residents' knowledge about coastal erosion, the use of kelp, and environmental issues in general. Moreover, it differed a lot per resident if they were willing to address coastal erosion issues and if they were concerned regarding the associated negative impacts. This variety in results was more or less the same in Quintero and Maitencillo.

Local businesses

Local businesses are a combination of restaurants, hotels, and surf- and diving schools. All of them are located near the shore, both in Quintero and Maitencillo. Consequently, they have an interest in the preservation of the beach and thus the mitigation of coastal erosion. The surveys did indicate that in general their awareness of this issue is lower compared to other stakeholders. This may be due to the fact that they feel like they are less directly affected by the coastal erosion.

Municipalities

From the expert interview in Appendix A and D, it became clear that the municipality of Puchuncaví (where Maitencillo is part of), considers coastal erosion as a problem. This is also why the municipality supports the research conducted by the kelp forest team, as they believe it is crucial to restore the marine environment and the coastal ecosystem. This support is not demonstrated through financial contributions, but rather by offering materials and access to work locations. Unfortunately, the municipality currently lacks plans to raise awareness about coastal erosion among residents, indicating an area that still requires improvement. (*Interview with Anna Cabagal*, 2024).

The municipality of Quintero is still less concerned with the coastal erosion problems. The interview showed that both the residents and the municipality mainly worry about the air pollution due to Quintero being in the "sacrifice area" of Chile (Seguel, 2023). As a result, they overlook the challenges of coastal erosion and show little interest in collaborating with the kelp forest research team. (*Interview with Maria Martinez*, 2024).

7.1.2. Regional stakeholders:

Quintero Bay is known for its industry and pollution. The industrial sector has significant financial influence and plays a key role in shaping the municipality's agenda. Despite its contributions to economic and environmental progress, the industrial hub of Quintero Bay remains burdened by severe pollution, poverty, and social tensions. Long-term environmental damage, particularly affecting marine ecosystems such as kelp forests, persists.

GNL

GNL Quintero is the southern hemisphere's first terminal for the reception, unloading, storage and regasification of liquefied natural gas (LNG) (GNL, n.d.). Since 2009, it has been a key contributor to Chile's energy diversification and security through the supply of LNG for residential, industrial and transport use. GNL Quintero has implemented community engagement initiatives, including supporting local fishermen, as part of broader efforts to address these environmental and social challenges (Salinas & GNL, 2013).

Puerto Ventanas S.A. (PVSA)

Puerto Ventanas SA, located in the Bay of Quintero, has established itself in the port industry as one of the most important bulk ports in Chile. Specialised in the handling of solid and liquid bulk, the port has a comprehensive docking service and advanced mechanised cargo storage and handling systems that place it at the forefront of the world's bulk ports. (PVSA, 2024). The port is affected by erosion, as the port is often closed due to high waves (*Interview with Milton Magnere*, 2024). Unfortunately, our meeting with Puerto Ventanas was cancelled shortly before it was supposed to take place. Because of the short timeframe of our project, it was not possible to reschedule this meeting.

7.1.3. National stakeholders:

Fuerzas Armadas de Chile (Chilean Armed Forces)
The Chilean Armed Forces is the unified military organisation compromising the Chilean Army, Navy, and Air Force. The Undersecretariat of the Armed Forces grants the aquaculture concessions and designates suitable areas for the those activities. Currently, there are 3.300 aquaculture concessions in Chile, including salmon, mussels, and algae as their main species. Aquaculture is regulated by the General Law on Fisheries and Aquaculture (LGPA), which outlines the legal framework for the import of hydrobiological resources, access to aquaculture areas, concessions, and environmental conditions (*Aquaculture - SUBPESCA.*, n.d.). In recent years, the Armed Forces have issued very few permits, leaving the use of aquaculture in coastal areas largely in the hands of local fishermen (*Interview with Milton Magnere*, 2024).

Ministerio del Medio Ambiente (Ministry of the Environment)
Chile's Ministry of the Environment is responsible for developing and implementing environmental policies, plans and programmes, while also overseeing the protection of biodiversity and renewable natural resources. Their goal is to strengthen the relevance - and thus the awareness - of environmental protection among the different ministries. Moreover, they try to strengthen policies and institutional capacities in the areas of biodiversity, water resources, environmental recovery, restoration, and decontamination. It is only in recent years that they have begun focusing on the challenges related to coastal erosion (Pica et al., 2019). Lastly, their mission is to strengthen the Environmental Assessment Service (SEA) since this allows for more efficient land use and better planning. (*Ministero del Medio Ambiente: MMA*, n.d.).

Servicio de Evaluación Ambiental (SEA)
SEA, translated to Environmental Assessment Service, is a decentralized public legal body aimed to contribute to sustainable developments by assessing environmental evaluation procedures (SEA, n.d.-a). Moreover, this body aims to operate in an efficient as well as responsible manner in which natural resources and humans are protected, all to ensure a sustainable and responsible usage of resources that contribute to Chile's development (Chile-Atiende, n.d.). The SEIA is a management instrument of the SEA, intended to protect nature and the environment, and regulated by law No. 19.300 in General Environmental Bases (SEA, n.d.-b). Overall, there are different Servicios de Evaluación Ambiental regionally, the SEA of the Valparaíso region is located in Valparaíso.

Ministerio de Economía Fomento y Turismo (Ministry of Economic Development and Tourism)
The Ministry of Economy, Development, and Tourism has the mission to promote a new model of productive development for the country, addressing the challenges of the climate crisis while focusing on the creation of quality jobs. This should strengthen the country's economy and improve their international position. Additionally, they aim to promote the modernization and competitiveness of the country's productive sectors, encourage private initiatives, and foster innovation to achieve sustainable and equitable growth (*Ministerio de Economía, Fomento y Turismo*, n.d.). By making use of Chile's unique coastal characteristics in combination with coordinating public policies on tourism, the Minisitry aims to promote sustainable tourism activity (*Historia - Ministerio de Economía, Fomento y Turismo*, 2023).

Servicio Nacional de Pesca y Acuicultura
Servicio Nacional de Pesca y Acuicultura, translated to The National Fisheries and Aquaculture Service (SERNAPESCA) is a public body of the Chilean Ministry of Economy, Development and Tourism. Additionally, the mission of this public body is to be monitoring the regulations of fishermen and aquaculture and its compliance, in terms of proper execution and protection of the environment (International-Waters, n.d.). Another goal is to safeguard the coasts in terms of sustainability and to protect the environment and its resources (SERNAPESCA, n.d.). Furthermore, the SUBPESCA is the regulatory body that is in charge of setting up these policies and also finances studies that are aimed to manage aquaculture activities with the Fisheries and Aquaculture Research Fund (FIP) (SUBPESCA, n.d.). Nevertheless, SERNAPESCA has been assessing fisheries in the area of Quintero which might have been damaged due to polluting actions by local industries (Elliott, 2014).

7.2. Power-interest-attitude analysis

Now that all key stakeholders have been identified, their power, interest, and attitudes will be analyzed. This analysis provides insight into each stakeholder's position regarding the kelp forest project. Furthermore, it reveals which stakeholders have the power to enact change and influence outcomes and possess significant interest in the project. It also shows whether they will use their power positively or negatively toward the project. These insights can be used to recommend valuable collaborations and identify potential challenges. Stakeholders with high power and high interest are considered key players, and collaborations with them should be managed closely.

After interviewing Milton and the environmental department of Puchuncaví, the first key player identified is the municipality of Puchuncaví. They have a high interest in saving the beaches and a positive attitude toward the project. As a result, they used their power to approve the project and support it by providing operational materials, locations, and promotional events. The second key player is the Ministry of Environment, they have a high power to regulate environmental initiatives and influence policy decisions for the kelp project, including permitting and funding. Their interest in protecting biodiversity and renewable resources aligns with the project's goals of enhancing marine ecosystems and promoting sustainable management. Consequently, they are likely to have a positive attitude toward initiatives that support biodiversity and sustainability.

In addition, analysis of local residents, fishermen, and local businesses through surveys conducted in SPSS revealed that fishermen are most aware of coastal erosion and recognize it as a problem. However, there is a notable difference in attitudes between fishermen from Quintero and Maitencillo. In Maitencillo, fishermen are willing to collaborate (*Interview with Ricardo Silva and Carlos Vega*, 2024), whereas those in Quintero are more distrustful and prefer to receive financial compensation before participating (*Interview with Fishermen's Federation of Quintero*, 2024). Consequently, the project was initiated in Maitencillo. Since the fishermen in Maitencillo are the legal owners of the kelp forest, they hold significant power, making it crucial to manage this relationship carefully

In contrast to the fishermen, the local residents and local businesses do not have such a high power position regarding the kelp project. The SPSS analysis concluded that local businesses have lower interest in the kelp forest compared to local residents. In addition, the local businesses don't really see coastal erosion as a problem for their business, they have a neutral attitude. Therefore they should be monitored, but are not key players. On the other hand the attitudes of local residents range from neutral to positive; most of them are aware of coastal erosion and see it as a problem, but for some, other issues, such as pollution and poverty, are considered more significant. Therefore, it is essential to keep the residents informed to prevent any concerns or conflicts that could hinder the project.

SERNAPESCA and SEA, regulatory organisations overseeing and evaluating fishing and aquaculture, support environmental improvement projects and hold a positive attitude toward the kelp forest initiative. However, they lack the power to fund the project or enforce broader change, so they should be kept informed, like local residents.

Finally, there are several stakeholders with significant power but lower interest, such as industries like Puerto Ventanas and GNL, the Ministry of Science, the Ministry of Economic Development and Tourism, the Chilean Armed Forces, and the Municipality of Quintero. Companies like GNL and Puerto Ventanas have considerable influence in the area, but they currently show no interest in the project and have not established any collaborations. As a result, they maintain a neutral attitude toward the kelp forest project (*Interview with GNL Quintero*, 2024).

The Ministry of Science holds high power in the kelp forest project because they provided essential funding of 200,000 Chilean pesos for the R&D project (*Interview with Milton Magnere*, 2024). Without this contribution, the project would not have been possible. Although they have a general interest in supporting research and development initiatives, they do not have a specific vested interest in the kelp project itself. Since their funding was a one-time contribution, they should be kept satisfied but do not require close management like key stakeholders such as the Municipality of Puchuncaví.

The Ministry of Economic Development and Tourism holds high power and has a positive attitude toward the kelp forest project, as the eroding of beaches negatively impacts tourism (Winckler et al., 2023). Although they recognize the importance of addressing coastal erosion, they have a medium

interest in the kelp forest project specifically, as they are currently focusing on promoting tourism through other means.

The Chilean Armed Forces has a lot of power, because they own the shore and granted the permit to the fishermen's association to realize the kelp project (*Interview with Milton Magnere*, 2024). They have interest in aquaculture in general, because they manage it, but don't have high interest in the specific kelp project in Maitencillo. Therefore their attitude ranges from neutral to positive. The Municipality of Quintero holds substantial power but currently has a negative attitude towards the project, because they declined to collaborate. However, after seeing results from Maitencillo or the following elections, their interest might increase in the future (*Interview with Maria Martinez*, 2024).

For stakeholders with high power but low interest, it is crucial to maintain a positive relationship and keep them satisfied. Their attitudes indicate their level of support or opposition to the project, which can significantly impact their willingness to cooperate. A positive attitude increases the chances of collaboration, while a negative or neutral stance may reduce their involvement in the project's implementation. Throughout the project, special attention should be given to stakeholders with high power, low interest, and a negative attitude, as they could pose challenges or obstruct progress if not managed carefully.

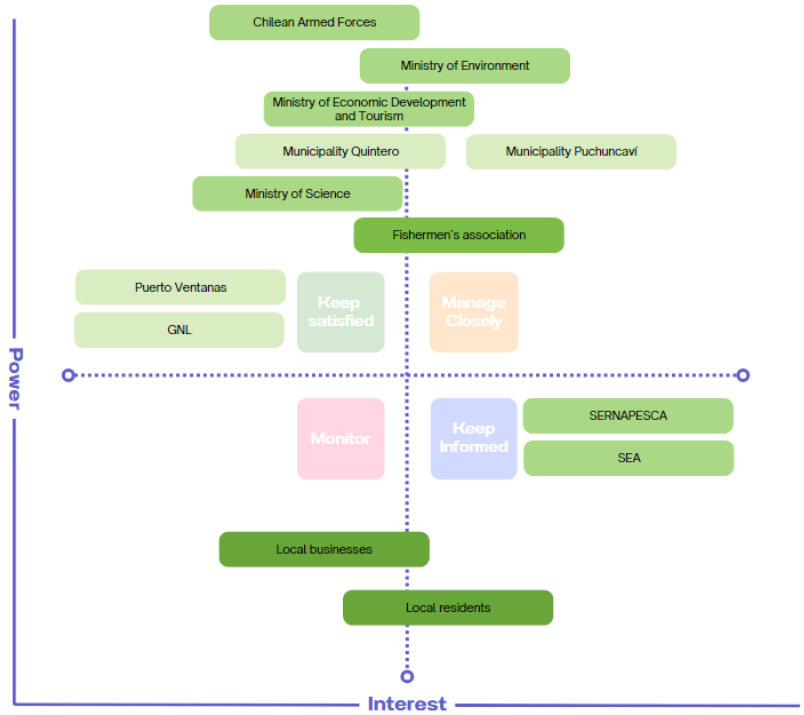


Figure 7.1: Power-interest grid

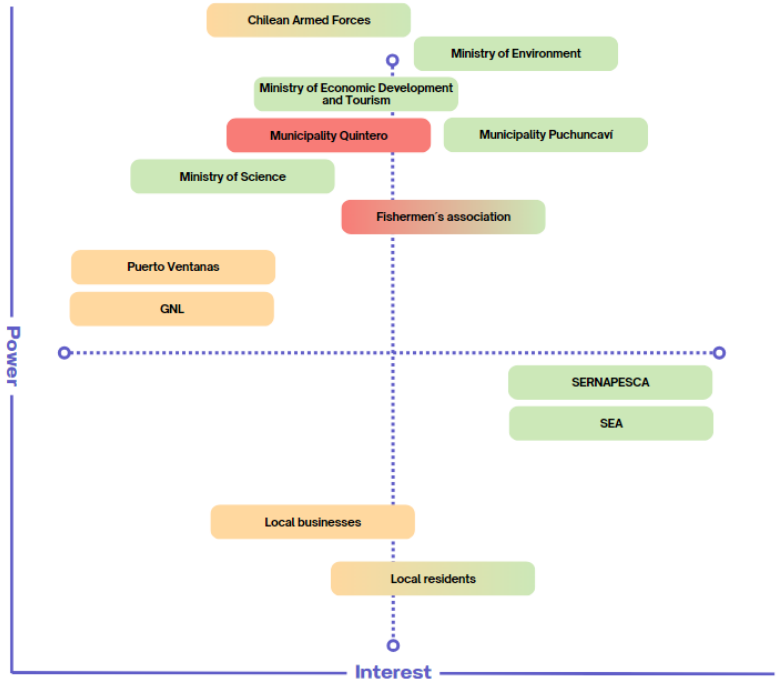


Figure 7.2: Power-interest-attitude grid

7.3. Relation diagram

The diagram below illustrates the relationships and interactions between the key stakeholders involved in the kelp forest project. It provides a comprehensive overview of all parties involved in the establishment and potential expansion of such a kelp forest project aimed at mitigating coastal erosion. The project itself is placed in the center to emphasize the numerous connections and collaborations required to initiate and sustain the kelp forest project.

The first notable detail is that the Chilean Armed Forces are positioned outside the main circle, reflecting their distinct role compared to other stakeholders. Since the military dictatorship from 1973 to 1990, they have been the owner of the entire Chilean coastline (Carmagnani, Drake, Caviedes, & Johnson, 2024). Consequently, they remain the sole authority capable of granting permits for aquaculture activities along the coast. In the years following the dictatorship, these licenses were mainly issued to fishermen's associations (Sindicato's). As a result, very few new licenses are granted today, leaving most of the coastal areas under the control of fishermen. However, any new activities they undertake must still be reported to the Armed Forces (*Interview with Milton Magnere*, 2024).

On the left side of the diagram, the Ministry of Science, the Ministry of Environment, the Ministry of Economic Development and Tourism, and the SERNAPESCA collectively represent the main collaboration of the central government. Together, they establish laws and regulations that the kelp project must comply with. In this regard, SERNAPESCA is a public body under the Ministry of Economic Development and Tourism, and together, they oversee regulations and establish policies that the fishermen's associations must follow when engaging in aquaculture activities (International-Waters, n.d.). The Ministry of Science provided initial funding for the project through ANID, the National Agency for Research and Development (*Interview with Milton Magnere*, 2024). This grant of US$200,000 allowed the project to start in Maitencillo, as detailed in Chapter 5.3.

The diagram also highlights the two municipalities involved: Puchuncaví and Quintero. The municipality of Puchuncaví is an active partner in the project, providing essential materials such as stones, sand, cement, and water for constructing the artificial reef. They also allocated the operational site and offered the cultural house for presenting the project to authorities. While Quintero is not yet an official partner, there is optimism that this will change as the project expands. For now, they contribute by offering valuable connections, such as facilitating the purchase of a boat. (*Interview with Milton Magnere*, 2024). In exchange for their support, the project's ultimate objective is to prevent coastal erosion in

these municipalities.

While there is no formal partnership with the Valparaíso regional government yet, discussions are underway regarding possibly obtaining the Competitiveness Innovation Fund, which could secure up to US$800,000 for the kelp project. Also in exchange for this funding, the project would focus on controlling coastal erosion in the region.

The relationship diagram also highlights two companies from the Quintero Bay: GNL and Puerto Ventanas. While interviews with representatives from GNL indicated that no formal collaboration with the kelp forest project currently exists, there is potential interest in future cooperation. For Puerto Ventanas was this confirmed by (*Interview with Milton Magnere*, 2024). Both companies face operational disruptions due to high waves and violent swells, which halt activities around 30% of the year. This shared challenge could motivate them to explore a partnership with the kelp forest research team to mitigate these issues. It was also revealed that GNL has specific agreements with the fishermen's association, offering them financial compensation for cleaning up the beaches (*Interview with Fishermen's Federation of Quintero*, 2024). This helps them with maintaining positive relationships with the local community. Additionally, they have supported the establishment of diving schools and aquaculture spaces in the fishing coves, while consistently welcoming residents to visit their visitor centers (*Interview with GNL Quintero*, 2024). The annual report of Puerto Ventanas reveals that they provide similar initiations (S.A., 2023).

As outlined in section 7.1.1, the fishermen's association (Sindicato) plays a crucial role as a key stakeholder in the start of the kelp forest project. This is due to their legal ownership (holders of the permit granted by the Armed Forces) of the coastal area designated for aquaculture, which includes the site where the kelp forest is located. Moreover, the Sindicato provides the project with material, seaweed structures, and all the human resources, including divers and fishermen (*Interview with Ricardo Silva and Carlos Vega*, 2024). In return, the project aims to enhance aquaculture by restoring biodiversity, which is of significant interest to the fishermen (*Interview with Milton Magnere*, 2024). The relations between the fishermen and the local businesses and residents are quite simple, as they often involve family ties or shared ownership of the businesses. As the *Interview with Milton Magnere* (2024) explained, the fishermen were often the ones who started the establishment of restaurants and shops near the coast, leading to their families living within the same community.

Lastly, the decentralized public legal entity known as SEA (Environmental Assessment Service) plays a crucial role in evaluating environmental procedures and assessing the potential environmental impact of activities and projects. They evaluate such activities related to the kelp forest project, the fishermen's association, and both GNL and Puerto Ventanas. Based on an Environmental Impact Study, the SEA determines whether the environmental impact of a project complies with current regulations (SEA, n.d.-c). If a project fails to meet these standards, the SEA can recommend preventive measures (Rodríguez-Luna, Vela, Alcalá, & Encina-Montoya, 2020). Therefore, as the kelp forest project expands, this assessment will need to be considered, and the approval process may require some time.

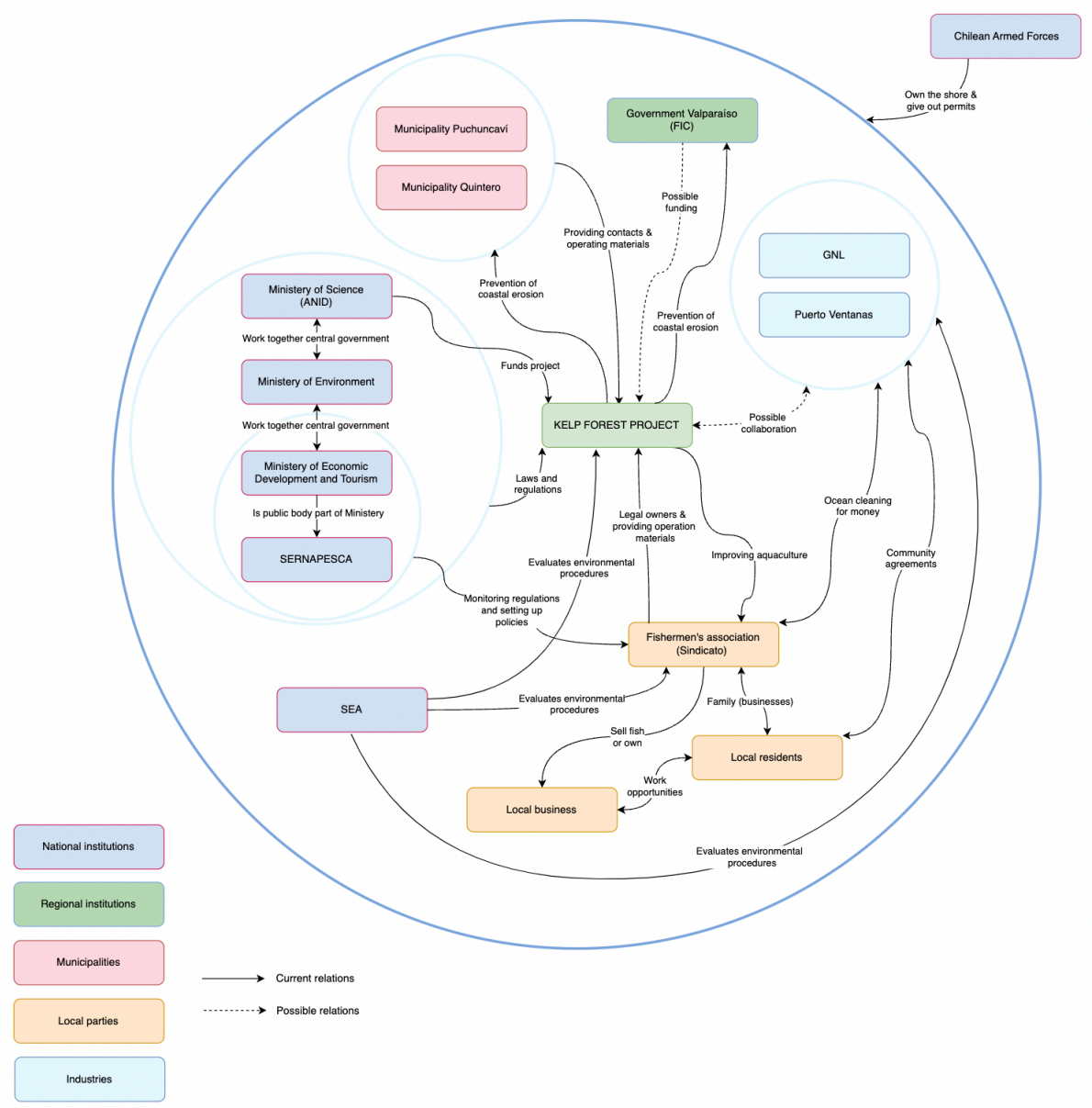


Figure 7.3: Relation diagram

8 Model

8.1. Goal

The main goal of this chapter is to describe the effect of the artificial kelp forest on gravity waves, where 1D and 2D SWAN-simulations show the wave attenuation of gravity waves. Energy density spectra are generated to show the redistribution of energy along different types of waves.

The modelling main research question is:

"What is the effect of kelp forest characteristics on the wave height, the wave energy flux and the energy density spectra, under different wave conditions?"

The main question can be divided into four sub-questions regarding the specific characteristics:

- What is the effect of the prototype kelp forest, that is currently being applied?
- What is the effect of increasing the size of the kelp forest?
- What is the effect of increasing the density of the kelp forest?
- What is the effect of the kelp forest with respect to the wave angle?

As these sub-questions address parameters that can be adjusted, their outcomes can be valuable for future expansion of the experiment.

The waves examined in this study are gravity waves. Classification of waves is done based on their periods, disturbing force (generation mechanism) and restoring force (damping of wave motion mechanism). Figure 8.1 shows the relative energy for each wave type. Wind-generated gravity waves, the waves that SWAN can solve, have a period of 0.25 to 30 [sec]. These waves are generated far offshore during storms, creating irregular oscillation. While travelling towards the shore they transform into swell waves due to frequency dispersion and frequency-dependent damping ((Judith Bosboom, 2023)).

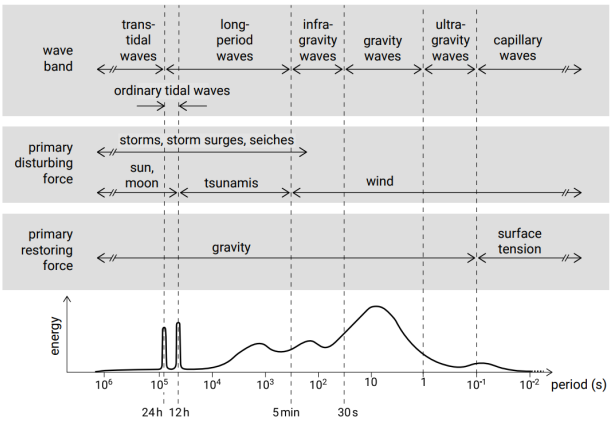


Figure 8.1: Relative amounts of energy classified by the wave periods (Judith Bosboom, 2023).

8.2. Methodology

First, SWAN is used in a one-dimensional mode to get a first glimpse of the effect on hydrodynamics when including a kelp forest. Then, a two-dimensional SWAN model is presented, where the Maitencillo field experiment is imitated in more detail. It is interesting to examine whether the hydraulic efficiency increases or decreases during extreme storm events, as those events are pivotal in the coastal development (see Chapter 3). Therefore, these extreme storm events are also modeled.

A plan is created in Section 9.3.4 for the kelp project's upscaling. It will be interesting to observe the actual hydraulic consequences upon scaling up the kelp forest. An extra large kelp forest, as well as a kelp forest with a bigger kelp density, is modelled in the 2D SWAN model.

Regardless of the model, a way to quantify the effectiveness of the kelp forest is needed. Two criteria will be used: the relative change in wave height and the relative change in wave energy flux.

The relative change in wave height shows what fraction of the wave height is absorbed by the kelp forest, compared to a situation without the kelp forest:

$$\left(\frac{H_{\text{out, kelp}}}{H_{\text{out, no kelp}}} - 1\right) \cdot 100\,\% \tag{8.1}$$

The relative change in wave energy flux shows what fraction of the wave energy flux is absorbed by the kelp forest, compared to a situation without the kelp forest:

$$\left(\frac{Ec_g\text{,out, kelp}}{Ec_g\text{,out, no kelp}} - 1\right) \cdot 100\,\% \tag{8.2}$$

8.3. Model settings

This section will cover the overarching model settings of both models, mainly focusing on the bathymetry, boundary conditions, physical processes and kelp characteristics.

Bathymetry

The near-coast bathymetry of Maitencillo is defined by data points of depth measurements. These measurements are taken in three different stages with different measurement systems. Figure 8.2 shows the stages in different colours. First, the whole area was measured by sailing the boat in a random path, until there is a significant amount of rough data points in the area of interest (blue). The second measurements were taken at the location where the kelp forest will be constructed and lines of data points parallel to the averaged shoreline (green). The scatter plot of these data points show the dense amount of data points in this area. Finally, the boat took measurements near the coastline to define the coast (orange). Because of the time difference between measurements, the tide will differ and therefore the relative depth changes. This results in large depth differences in the bathymetry. Besides these tide differences, smaller waves also give differences in depth measurements within a wave period.

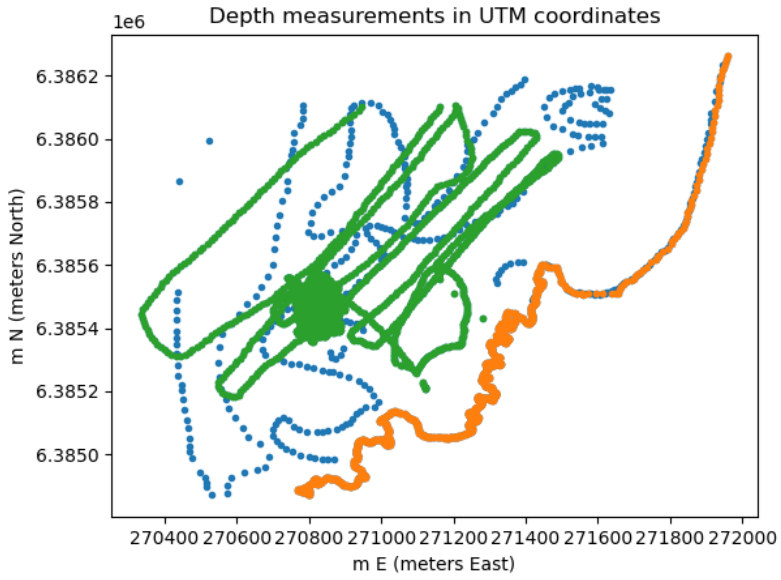


Figure 8.2: Datapoints of depth measurements where three different colours indicate three different stages

To create a bathymetry form these raw datapoints, the datapoints are extrapolated. Due to the inconsistent way of measuring the raw datapoints, this leads to large unrealistic jumps in the depth profile, as can be seen in the left handside of Figure 8.3. To create a more realistic bottom profile, the data has been smoothed using Surfer software (*Surfer*, 2024). After a few tries of different smoothened bathymetries, the one shown in Figure 8.3 and Figure 8.4 is used. As the results could still be sensitive to bathymetric inaccuracies, the criteria to assess the effectiveness of the kelp are determined at one location, so that the bathymetric effects are excluded (see Chapter 8.2).

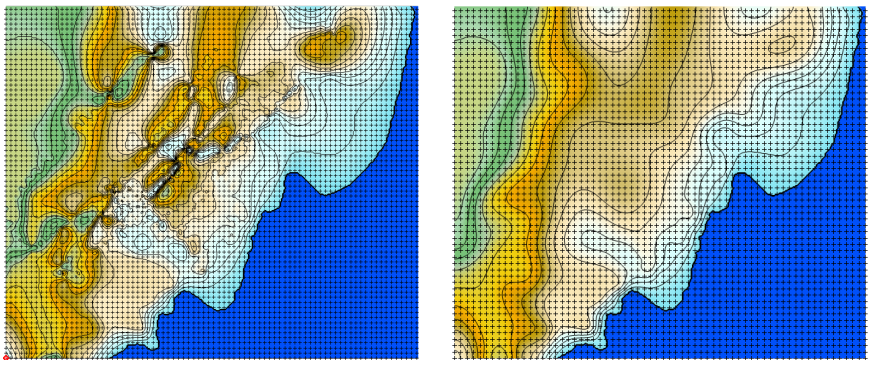
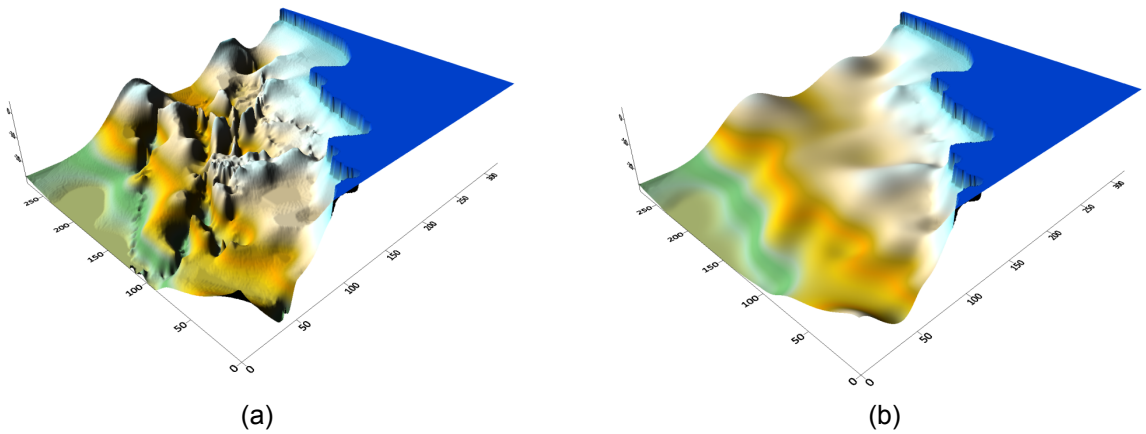


Figure 8.3: (a) Contour before smoothening (b) Contour after smoothening



(a) (b)

Figure 8.4: (a) Bathymetry before smoothening (b) Bathymetry after smoothening

Boundary conditions

The spectral range of the models is a full circle with 180 meshes of 2 degrees in the θ-space. This represents the spectral directional resolution. The range of frequency used in the calculation is set from 1/30 [Hz] to 1/3 [Hz] because this represents wind generated waves.

The parametric spectra are defined at the offshore side. Under normal conditions, the mean significant wave height is equal to 1.55 [m] and the mean peak period is equal to 13.13 [s] as can be seen in figure 4.2. The coefficient of directional spreading is set to 2 [°] for both models as this value is required when dealing with swell waves (TU Delft, 2024).

The shape of the spectra (both in frequency and direction) at the boundary of the computational grid have been defined with a JONSWAP spectum. All default values have been used except the value of γ, which is 1.42 at Caleta Beach (Oceanica & de valparaiso, n.d.).

To assess the effectiveness under different wave conditions, the models will also be run under storm conditions in both models. Martínez et al. (2017) described extreme storm events as storms with wave heights higher than the mean wave heights plus two standard deviations. 45 years of wave data at Maintencillo yields an average extreme storm wave height of 2.94 [m] and a storm peak period of 12.41 [sec].The latter is obtained by taking the average of the peak periods corresponding to the extreme wave heights.

Physical processes

SWAN contains physical processes that can be included in the model, namely: quadruplet wave-wave interaction, wind, whitecapping, bottom friction, depth-induced wave breaking, nonlinear wave-wave interaction triads, wave-induced set up, Bragg scattering and turbulence. Each of these processes will now be adressed with an explanation regarding why they are included or excluded in both models.

Wind is excluded in both models, since the focus is on waves with a period of approximately 13 seconds. These waves have wavelengths that are too long for wind to transfer energy to the waves. As swell waves are not locally generated, the effect of local wind be neglected. In SWAN, quadruplet wave-wave interactions do not appear without an acting wind force. Therefore, quadruplet wave-wave interaction is also turned off in both models.

In both models a reduction of energy is present by including depth-induced wave breaking in shallow water, steepness-induced wave breaking (otherwise known as whitecapping) and bottom friction. For depth induced breakin, the method of Battjes and Janssen (1987) (TU Delft, 2024) with a breaker index of γ = 0.78 (Judith Bosboom, 2023) is used and for whitecapping the method of Alves and Banner (2003) with default values. Bottom friction is described by the method of Smith et al. (2011) (TU Delft, 2024). Here friction depends on the formation of ripples and the grain size where the specific gravity of sand is 2.65 and a diameter of 0.0003 [m]. Due to wave breaking the momentum gets transferred into the water column, causing set-up. Set-up has therefore also been added to the models. By default the wave-induced set-up is zero at the deepest point and from there a constant is added.

Triads transfer energy from lower to higher frequency (Neill & Hashemi, 2018). The energy transfer in this process can take place over relatively short distance and can dramatically change single peaked

spectra into multiple peaked spectra, which has frequently been observed in the field (TU Delft, 2024). In SWAN the triad interactions are included and described with the DCTA method of Booij et al. (2009) with default parameter values.

Bragg scattering is excluded in the models. This phenomenon is caused by small-scale variations in the bathymetry. It leads to scattering of the waves, provided that the variations (such as ripples) are of the same order of magnitude as the wave lengths. In the model runs, the wavelengths are very big, which causes eventual ripples to be not relevant for this type of phenomenon. This means Bragg Scattering does not have to be accounted for (TU Delft, 2024).

Finally, turbulence is included. For nearshore locations, a turbulent viscosity of 10^{-2} $[m^2/s]$ may be used, which is what will be done in the SWAN models (Judith Bosboom, 2023).

Kelp characteristics

The kelp forest that is being planted in real life for the field experiment is modeled in both 1D and 2D. The kelp forest has dimensions of 75 [m] by 40 [m]. The location of the kelp forest is shown in Figure 8.5. The forest is located approximately 560 meters from Caleta Beach. The two lines (one towards Caleta Beach and one in the direction of the waves) cross each other in the middle of the kelp field. On these lines the colored dots show the locations of interest just before, after and near the coast. In the 1D and 2D model of SWAN the effect of the kelp forest on the hydrodynamics is determined in the points shown in Figure 8.5. The points are located on two lines. The red line is drawn between the kelp forest and the beach of interest, Caleta beach, to get an understanding of the hydrodynamic characteristics of the waves arriving at Caleta beach. The green line is drawn under an angle of 10 degrees. The same angle as the angle of incidence of the waves. The exact coordinates of the data points can be found in Table 8.1.

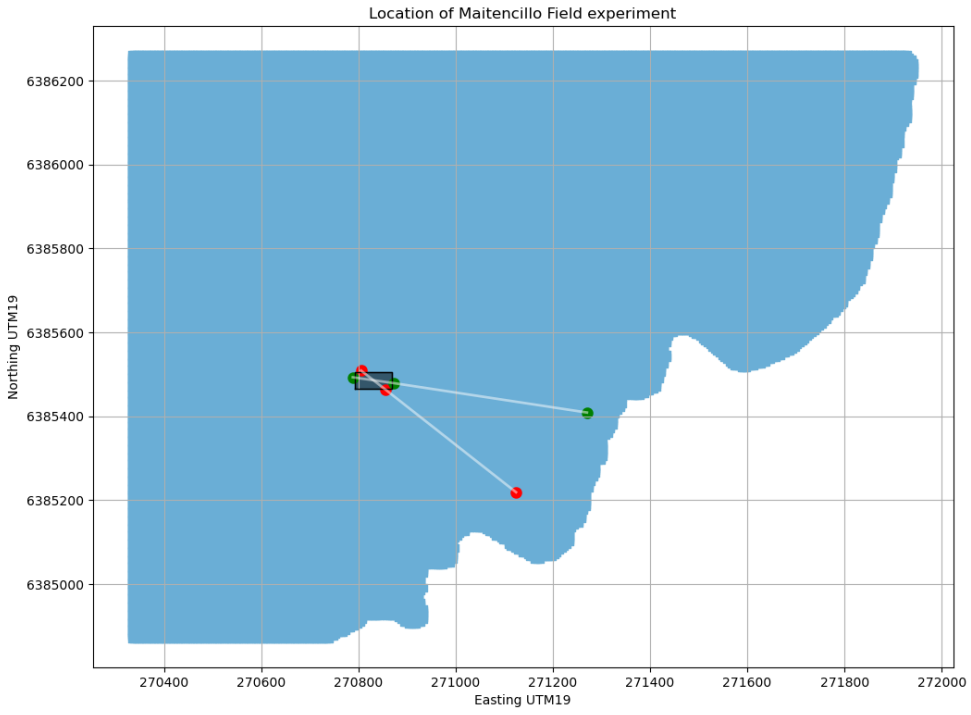


Figure 8.5: Kelp location in UTM coordinates indicated with a black box. Green line towards Caleta Beach and orange line parallel with the main wave direction

Line	Data point	Latitude (S)	Longitude (W)	Water depth [m]
Towards Caleta beach (red line)	Before kelp	270783	6385527	9.42
Towards Caleta beach (red line)	after kelp	270891	6385429	7.29
Towards Caleta beach (red line)	Near coastline	271216	6385133	2.10
In wave direction (green line)	Before kelp	270749	6385499	9.90
In wave direction (green line)	After kelp	270929	6385468	11.75
In wave direction (green line)	Near coastline	271229	6385415	8.41

Table 8.1: Coordinates of the data points shown in Figure 8.5.

In the kelp forest, the average water depth is equal to 11 [m]. Because the seedling lines are located 1 [m] above the bottom, as mentioned in Chapter 5.2, (h_v) is equal to 10 [m]. The following properties shown in the table below describe the kelp used in this project. They have been explained in Chapter 5.

Abbreviation	Definition	Value
Iveg	Vegetation method	2 (Jacobsen)
height	Kelp height	10 [m]
diamtr	Kelp diameter	0.03 [m]
nstems	Kelp density	4 $[u/m^2]$
C_d	drag coeficient	0.5 [-]

Table 8.2: Vegetation parameters

No studies have been performed yet to find the proper drag coefficient of Giant Kelp. Therefore multiple assumptions have been made to calculate the drag force of Giant Kelp:

- Giant Kelp is a rigid cylinder.
- The bulk C_d is a summation of the individual C_d of all plants separately.

Using a SAS model the drag coefficient has been calculated of each plant/rigid cylinder individually. In the figure 8.6 the bulk drag coefficient is plotted out against the height for different densities. It results in Cd = 0.5 [-].

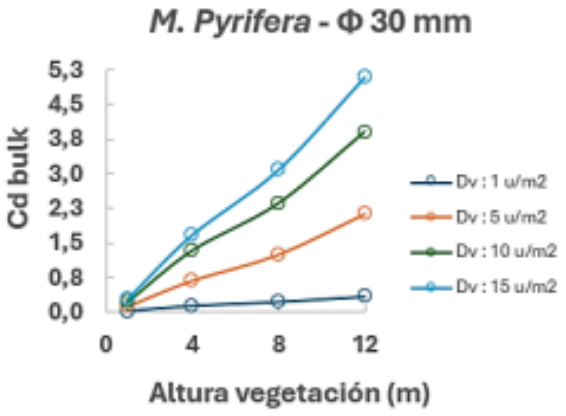


Figure 8.6: Bulk C_d plotted against h_v for a diameter of 0.03 [m]

The actual drag coefficient of Giant Kelp is now being researched. For now the assumed C_d = 0.5 is used, later this model can be used with the new correct drag coefficient.

To calculate the drag force of vegetation, method 2 (Jacobsen) has been chosen. Jacobsen, McFall, and van der A (2019) did research into different dissipation methods for the wave attenuation. Method 1 (Suzuki) is widely used in SWAN where the frequency dependent dissipation is simply related to the distribution of the wave power density. The new method found by Jacobsen et al. (2019) is a dissipation model based on linear super-position of the velocity contribution of all frequencies. Jacobsen et al. (2019) found that Suzuki models the dissipation due to vegetation well in conditions where kh < 1 and vegetation emerges. These conditions are very common during storms. The method of Jacobsen et al. (2019) more accurately captures the underlying physics for dissipation from submerged vegetation in milder wave conditions where kh > 1. The model can also be used for bulk. The SAS model uses a wave velocity of 1 m/s to calculate the C_d. Combining this velocity with the mean period found in figure 4.2 and the depth at the location of the vegetation we can find that kh > 1. The Giant Kelp at the site is also submerged. Due to these two reasons it is chosen to use the method of Jacobsen instead of Suzuki for the vegetation computation.

8.4. Model-specific approach

This section will cover the model settings that are specific to the 1D and 2D model.

8.4.1. 1D-SWAN model

The 1D SWAN model is intended to show globally what the effect of the kelp forest is. The specific model settings will now be discussed.

Bathymetry

The model runs in 1D are carried out in two directions: one through the kelp forest towards Caleta Beach, the beach of interest, and one trough the kelp forest under an angle of 10 [°], the same angle under which the waves are incident (see Figure 8.5). The effect of the kelp forest is examined by comparing the situation with kelp and without kelp under the exact same conditions in both directions.

The bathymetric profiles are generated by tracing the two transects across the 2D bottom profile and assigning depth values along these transects. Each line contains 10,000 grid points to achieve a highly detailed and accurate representation of the bathymetry.

The caleta line is 864 [m] long. It has 10000 grid points, 9999 meshes, yielding a mesh size of 0.08641 [m]. The kelp forest is stretched over a length of 71 m, located between (270809, 6385506), (270852, 6385466). The bathymetry, including the location of the vegetation, is visible in Figure 8.7.

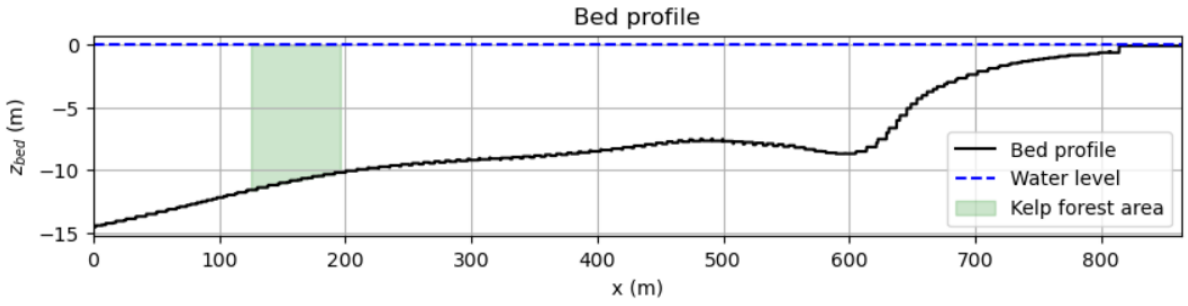


Figure 8.7: Bathymetry and kelp forest location along 1D model to Caleta Beach

The same procedure is followed to obtain a 1D bathymetry for the 10 [°] direction. This grid has 10000 points and 9999 meshes as well, but with a length of 914 [m] and a mesh size of 0.09141 [m]. The kelp forest is now stretched over a length of 76 m, located between (270793, 6385492) and (270868, 6385479). The bathymetry, including the location of the vegetation, is visible in Figure 8.8.

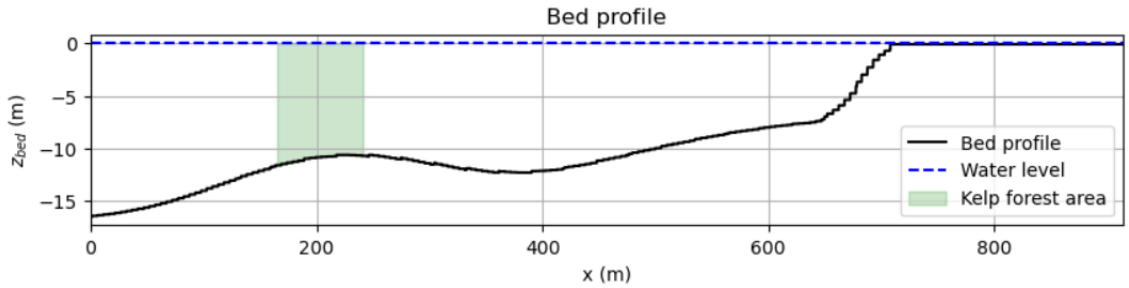


Figure 8.8: Bathymetry and kelp forest location along 1D model in 10 [°] direction

Model runs

Both 1D models will first be run out under 'normal' conditions, with an average peak period and average significant wave height. Subsequently, runs are being done under storm conditions, as mentioned in Chapter 8.3. All 4 situations will also be run without an kelp forest, to be able to make a comparison to a situation without a forest. An overview of the 4 runs can be found in Table 8.3. One important thing to note is that the waves are modelled as if they are incident straight from the left in both directions, although this is not true for the Caleta direction in real life. This means the results can not be interpreted as realistic for the real case. However, they will show the effectiveness of the kelp forest if it had been placed in front of Caleta beach.

Addition	Run 1	Run 2	Run 3	Run 4
Direction	Caleta	Caleta	10 [°]	10 [°]
Wave conditions	Normal	Storm	Normal	Storm

Table 8.3: Different 1D runs

8.4.2. SWAN 2D model

The objective of the 2D SWAN model is to provide a deeper understanding of the role of kelp forests in wave attenuation. Unlike the 1D model, the 2D approach incorporates more complex physical processes such as refraction, offering a more comprehensive and realistic representation of wave dynamics. Furthermore, the 2D model enables the visualization of energy distribution across the area behind the kelp forest, providing valuable insights into wave-vegetation interactions.

This section follows a similar structure as the previous one, beginning with two subsections that are applicable to both cases, with and without vegetation. It then delves into the application of vegetation in the model, and finally, it addresses extreme conditions. The three scenarios examined involve extreme wave heights, representing storms, an expanded kelp forest and an high kelp density.

run	Kelp area size $[m^2]$	Wave conditions	Kelp density $[u/m^2]$
Run 1	-	normal	-
Run 2	75x40	normal	4
Run 3	-	storm	-
Run 4	75x40	storm	4
Run 5	150x80	normal	4
Run 6	200x120	normal	4
Run 7	150x80	storm	4
Run 8	200x120	storm	4
Run 9	75x40	normal	8
Run 10	75x40	normal	16
Run 11	75x40	storm	8
Run 12	75x40	storm	16

Table 8.4: Runs in 2D model

Bathymetry and boundary conditions

For the development of the 2D SWAN model, the smoothened data shown in Figure 8.4 is deployed in a structured grid.

The spectral range and range of frequency used, are identical to the 1D model. The same goes for the parametric spectra. In reality, waves approach the site from the northwest (NWW) with an angle of 10 degrees as can be seen in Figure 8.9. The wave characteristics of the waves entering are measured at (-32.645613, -71.443746) which is not at the boundary, but below the kelp forest. The assumption has been made that the waves entering the boundary have the same characteristics. This assumption should be kept in mind when looking at the results.

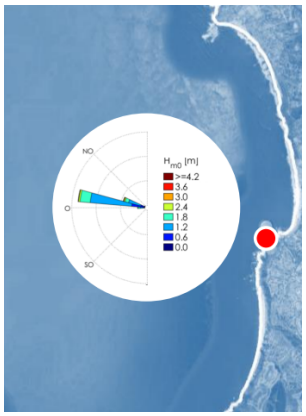


Figure 8.9: Wave angle of incidence

In the 2D model the boundaries of the computational spatial grid are defined for the different sides. The right side boundary consists of land which does not generate waves and it absorbs all incoming wave energy in SWAN. The left side of the grid is set open and the Jonswap wave spectrum is defined. The upper and lower side boundaries are largely consisting of water where the wave conditions are unknown. When no condition is given, SWAN assumes that no waves enter the area and that waves can freely leave the area. This can cause computational errors near these boundaries. To avoid false conclusions in our model, the area of interest needs to be sufficiently far away from this boundary.

Physical processes

As in the 1D model, energy dissipation is a result of depth-induced wavebreaking, whitecapping and bottom friction. However Set-up is not included in the 2D model. Triad waves have again been added as an energy conservation term. Because, when making this model, a interest lies with finding if the energy distributes after passing the kelp forest, the triad wave-wave interactions are of great importance.

Refraction have also now been added to the model. Now possible because working in 2D. Refraction is default. Diffraction has been left out of the model this is because no clear shadow zone is created behind neither the kelp forest or the headlines. The kelp forest is to permeable to create a shadow zone and the headlines are not in between the wave and Caleta beach to create a shadowzone.

Kelp forest

In the simulations that include vegetation, a kelp forest is introduced into the model. The kelp forest is positioned according to the coordinates provided in Section 5.2. However due to a mesh size of 5 meters, the kelp forest location has an uncertainty of 2.5 meters.

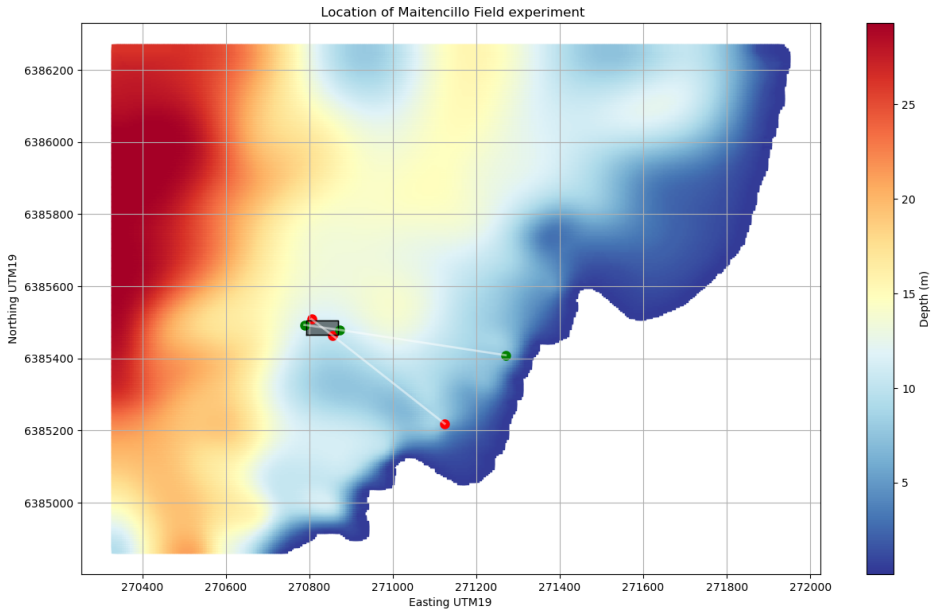


Figure 8.10: Kelp 75 x 40 [m] location in UTM coordinates indicated with a black box. Green line towards Caleta Beach and orange line parallel with the main wave direction

Storm conditions

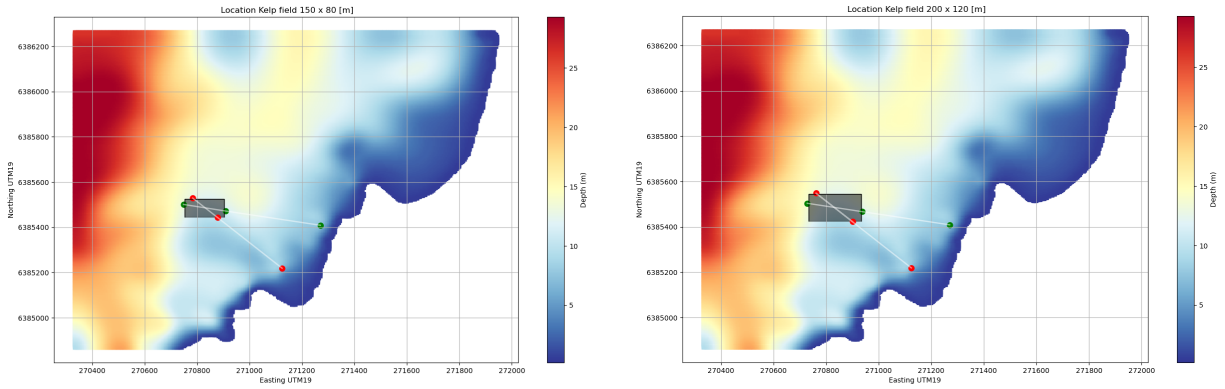
In addition to the baseline simulations, two models were developed—one with and one without kelp—under storm conditions. These conditions were simulated by adjusting the boundary conditions to reflect a significant increase in wave height, representing a typical storm scenario (see Chapter 8.3).

Enlarged kelp forest

The kelp forest is expanded twice in order to examine the relationship between the kelp forest's size and the wave height, the wave energy flux, and the energy density spectra under different wave conditions. The kelp forest's initial dimensions are 75 [m] by 40 [m], with an area of 3000 $[m^2]$. The following enlargements are carried out:

- Multiplication of 4 yielding an area of 12000 $[m^2]$ with dimensions 150 [m] x 80 [m].
- Multiplication of 8 yielding an area of 24000 $[m^2]$ with dimensions 200 [m] x 120 [m].

For the second enlargement the dimensions of the kelp forest are not multiplied by the same factor. Therefore the shape and middle point of the area also changes slightly in comparison to the shape and middle point of the other sizes. This was necessary because, if the dimensions are not multiplications of the mesh size of 5 meters, SWAN will select the closest gridpoint close to the kelp forest's corners, changing the area's size. In order to examine the effect of the size, the precise area's size is thought to be more crucial then its precise shape.



(a) (b)

Figure 8.11: (a) Area of 12.000 m² (x4) (b) Area of 24.000 m² (x8)

Increased density

In order to examine the effect of increasing the density of the kelp forest on the wave height, the wave energy flux and the energy density spectra under different conditions, the density is increased twice. The kelp forest's initial density is 4 and it is increased to v of 8 and 16 while keeping all other parameters constant.

Position of the kelp forest

The two lines drawn in the area are used to examine the efficiency of the location of the kelp. By examining the third point on each line one can examine which part of the coastlines experiences most effect of the kelp forest.

8.5. Hypothesis

Each of the four sub-questions will now be addressed by means of a hypothesis.

8.5.1. Prototype

The wave height reduction after the kelp of 75 x 40 m forest during normal wave conditions is between 10 and 20 %. Short waves attenuate more than long waves which will cause a shift of the peak of the power-density spectrum towards lower frequencies.

The wave height will decrease significantly after passing through the kelp forest. Based on Zhu, Lei, Huguenard, and Fredriksson (2021) and Zhu, Huguenard, Fredriksson, and Lei (2022), a wave height reduction of approximately 10 - 20% is expected right behind the kelp forest. Further behind, the effect will diminish again due to refraction, shoaling and directional spreading.

Wave energy is proportional to the wave height squared, so as a result, the wave energy flux will decrease even faster than the wave height. ((Judith Bosboom, 2023)).

According to Mendez and Losada (2004), dissipation by vegetation is inversely correlated with the period. This leads to the hypothesis that short waves will attenuate more than long waves, which will cause a shift of the peak of the power-density spectrum towards lower frequencies. The relative contribution of lower frequencies will increase due to the selective attenuation.

8.5.2. Increased kelp forest size

Increasing the size of the kelp forest will eventually lose its efficiency as the waves dampen out.

Formula 5.2 shows that energy dissipation by vegetation scales with the wave height cubed. A wave loses height as it penetrates through a kelp forest. This means that for increasing size, the kelp forest becomes less efficient in attenuating the wave heights. The wave energy flux reduction will become more efficient even slower than the wave height reduction, as it scales with the wave heights squared.

8.5.3. Increased density

Increasing the density of the kelp forest will eventually lose its efficiency as the waves dampen out.

Kelp density and energy dissipation per unit area by vegetation scale linearly (see Formula 5.2). However, the same reasoning as the one for the kelp forest size holds here. As the increase in kelp density causes more dissipation, less high waves penetrate, which in turn dissipate less further down in the forest. Therefore, the efficiency of the kelp forest increases for increasing kelp density, but again with an exponentially decreasing increase.

8.5.4. Position of kelp forest

The effect of the kelp forest is most in the direction of the incident wave angle.

The kelp forest length in the direction of the waves is expected to be the most important for wave energy dissipation, as waves are most energetic in this direction. This long stretch of kelp should therefore be aligned between the incoming wave and the part of the coastline that requires the most protection.

8.6. Results

This section addresses the relative results of the models. Both models are discussed separately.

8.6.1. 1D-SWAN model

First, the results of the 1D model are discussed. For every run, the difference in wave height is computed between the case with and without vegetation. This is done for every point specified in Table 8.1. The results can be seen in Table 8.5. Naturally, there is no change in wave height before the waves have entered the kelp forest. After the kelp forest, a relative change in wave height can be observed, which stays more or less the same until the breaker zone. Depending on the local bathymetry, it might increase or decrease slightly.

Data point	Run 1 *Normal conditions - Caleta*	Run 2 *Storm conditions - Caleta*	Run 3 *Normal conditions - 10 [°]*	Run 4 *Storm conditions - 10 [°]*
Before kelp	0.00	0.00	0.00	0.00
After kelp	-5.17	-9.31	-5.53	-9.90
Near coastline	-5.25	-8.54	-5.62	-9.76

Table 8.5: Relative change in wave height [%] at several locations for both 1D directions

Runs 2 and 4, the runs under storm conditions, have the biggest changes in wave height. Clearly, the effectiveness of the kelp forest increases when the height of the incoming waves increases. The development of the significant wave height of run 4 is visible in Figure K.4.

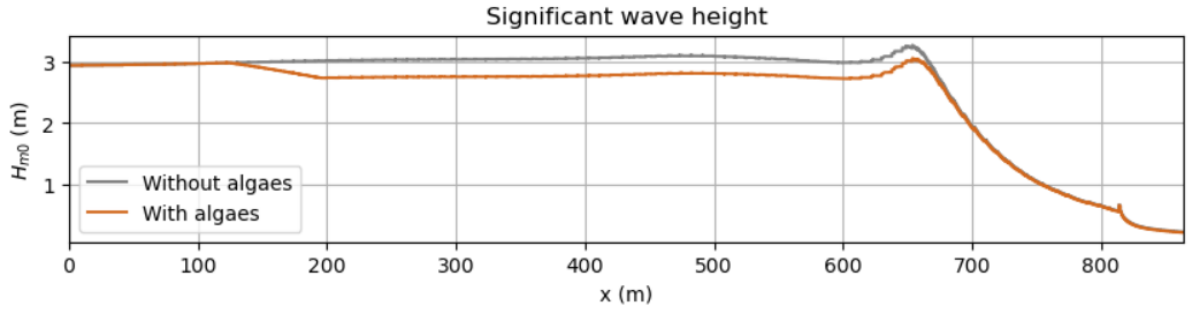


Figure 8.12: Significant wave height development of run 4 (10 [°] - storm conditions)

In addition to the change in wave height, the change change in wave energy flux caused by the kelp forest is determined for both directions. These values are visible in Table 8.6. Again, the effectiveness of the kelp forest is biggest in the runs with storm conditions.

Data point	Run 1 *Normal conditions - Caleta*	Run 2 *Storm conditions - Caleta*	Run 3 *Normal conditions - 10 [°]*	Run 4 *Storm conditions - 10 [°]*
Before kelp	0.00	0.00	0.00	0.00
After kelp	-10.07	-17.72	-10.74	-18.78
Near coastline	-10.22	-16.30	-10.91	-18.50

Table 8.6: Relative change in wave energy flux [%] at several locations for both 1D directions

The different forms of energy dissipation of run 4 are visible in 8.13. Here, one can clearly distinguish the contribution of each type of dissipation to the total dissipation.

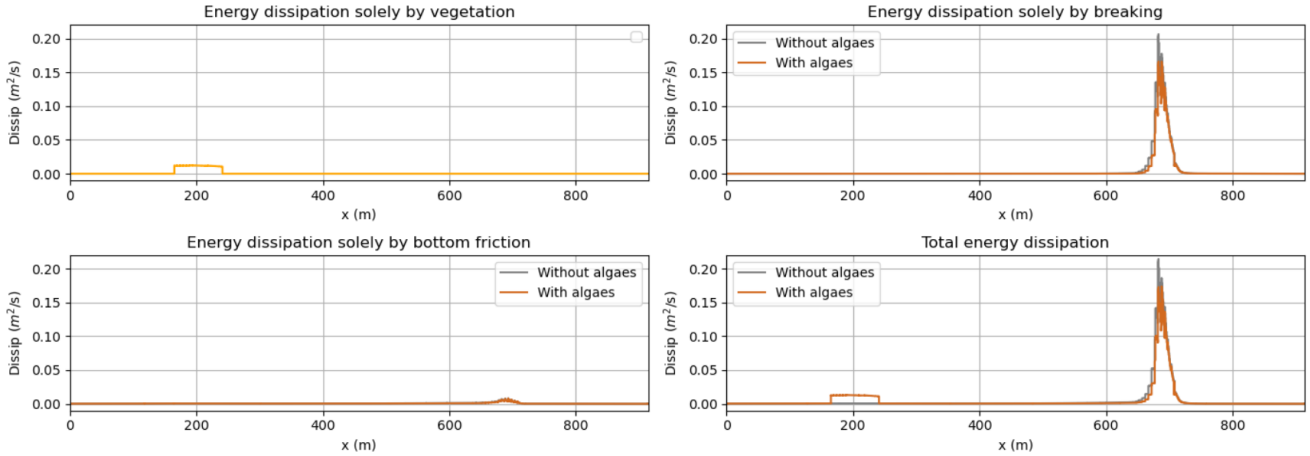


Figure 8.13: Significant wave height development of run 4 (10 [°] - storm)

Finally, the energy density spectra of all four runs have been computed. The results are visible in Figure 8.14. Under storm conditions, the energy clearly reduces and the energy peak shifts to lower frequencies, and this does not change much towards the coastline. Under normal conditions, however, the wave energy near the shore recovers to levels similar to before the kelp forest again. This is because these waves experience a bigger increase in wave height due to shoaling (see Appendix K).

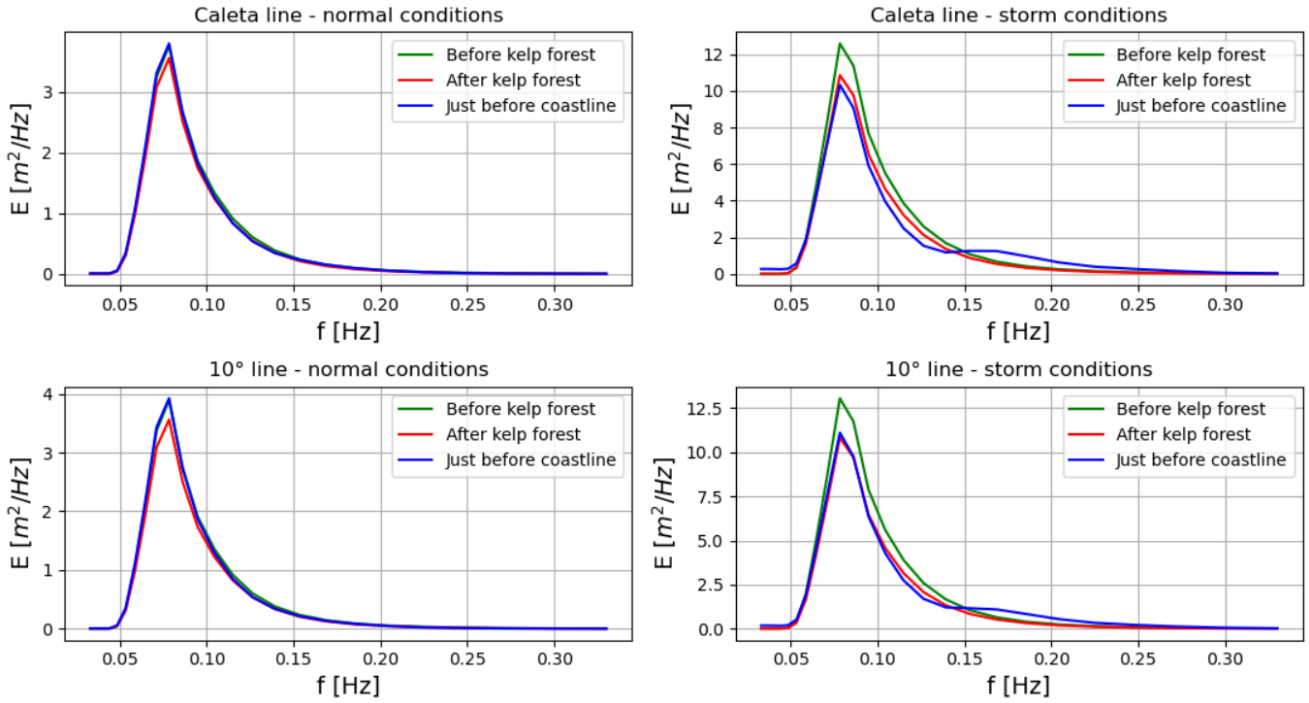
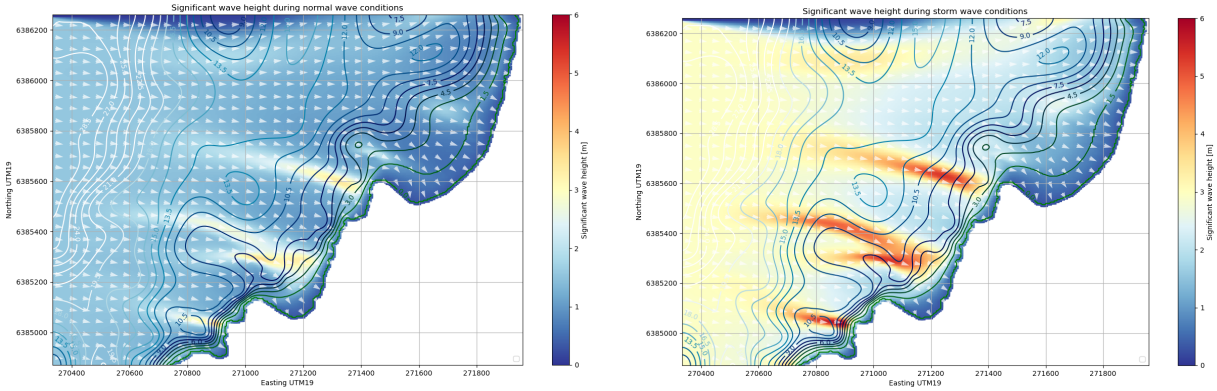


Figure 8.14: Variance density spectra

The next step should be validating the 1D-SWAN model. However, due to the unique way this experiment has been set up, attempts to carry out runs with a benchmark model were unsuccessful. This reduces the reliability of the absolute model results. Relative results however, can still be used and should give a fair image of reality.

8.6.2. 2D-SWAN model

First, the significant wave height of the normal and storm conditions are modeled on the bathymetry to obtain a reference for the situations where a kelp forest is included. Figure 8.15 shows the significant wave height for both cases, with the direction of the waves being indicated with arrows. For the storm conditions it is assumed that the storm wave direction is the same as the normal wave direction in order to only investigate the difference in wave height and period. What can be seen is that for both wave conditions the significant wave height increases at the same location due to the bathymetry. The direction of the waves changes as well, from the offshore direction of 10 degrees to a direction perpendicular to the coastline, due to refraction towards lower depths.



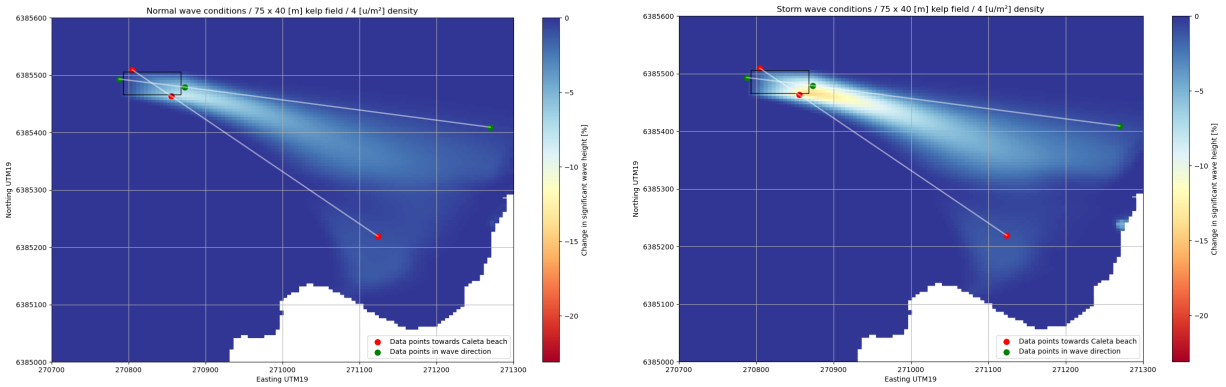
(a) (b)

Figure 8.15: (a) Significant wave height during normal wave conditions (b) Significant wave height during storm wave conditions

To check the pattern of the significant wave height, the contour plot is added to Figure 8.15. As can be seen, the bathymetry does not increase with depth constantly along the shoreline. These irregularities in the bathymetry cause wave refraction and shoaling offshore as the whole area is considered to be in shallow water. The differences in the bathymetry are the result of depth measurements that were taken at different times and with different measurement systems as described earlier. The effect of these extremely high wave heights are excluded by calculating effectiveness of the kelp forest at one specific location, as described in Chapter 8.3.

Model of field experiment

To imitate the field experiment of Maitencillo, the kelp forest is added to model. Figure 8.16 shows the wave height reduction of the kelp forest for normal and storm wave conditions. When comparing the changes in significant wave height in the cases with and without kelp forest, only the effect of the kelp forest on the wave height is visible. The left plot is the result during normal wave conditions and the right plot during storm wave conditions. The color scale is the same as for normal wave conditions and the hydraulic efficiency is significantly increased. What the plot shows is that the hydraulic efficiency is largest just behind the kelp forest in the direction of the waves and spreads out when approaching the coast. This means that a larger area along the coastline is influenced by the kelp forest compared to the size of the forest itself. What also can be noticed is that the change in significant wave height is zero in front of the coast. This can be explained by waves breaking around this area which results in zero wave height with and without kelp forest.



(a) (b)

Figure 8.16: (a) Change in significant wave height for normal wave conditions [%] (b) Change in significant wave height for storm wave conditions [%]

The table 8.7 shows the relative changes of the significant wave height with and without vegetation at the specific points. What is important to notice is that the values at the points differ from the values calculated from the plots of Figure 8.16. This is because the plot is created with the output of the grid in SWAN where all grid points are an average over the mesh size which is 5 by 5 [m]. The specific points on the lines give the exact value at the specific locations.

Data point	Run 2 *Normal conditions - Caleta*	Run 4 *Storm conditions - Caleta*	Run 2 *Normal conditions - 10 [°]*	Run 4 *Storm conditions - 10 [°]*
Before kelp	-0.23	-0.43	0	0
After kelp	-6.06	-10.45	-6.33	-11.21
Near coastline	-1.04	-1.22	-0.51	-0.90

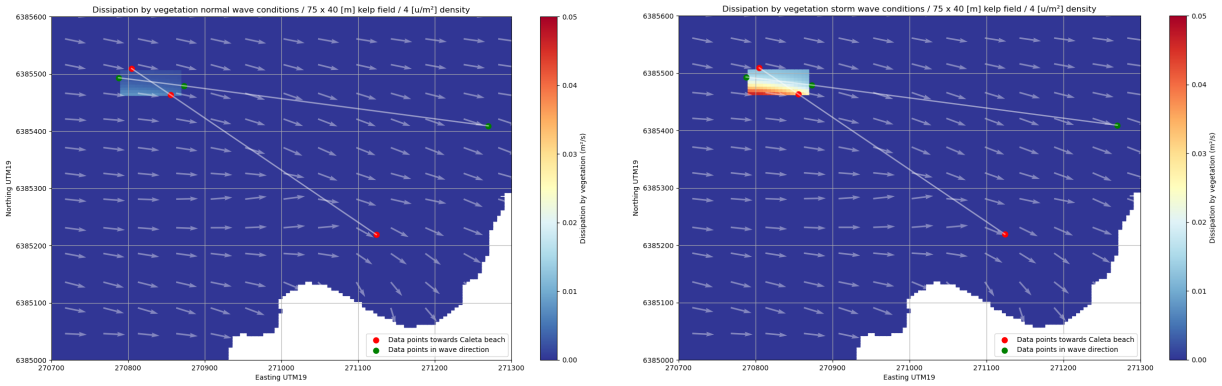
Table 8.7: Changes in significant wave height at each point [%]

The increase in the wave height reduction is related to the significant wave height. At each point of the two lines the significant wave height is given in Table 8.8. What can be seen is that the wave height decreases when following the 10 degrees line from offshore to onshore. Along the Caleta line, the wave height first increases and decreases nearshore. This can be explained by the path differences the waves follow before reaching the three points of the Caleta line.

Data point	Run 2 *Normal conditions - Caleta*	Run 4 *Storm conditions - Caleta*	Run 2 *Normal conditions - 10 [°]*	Run 4 *Storm conditions - 10 [°]*
Before kelp	1.63	3.06	1.84	3.45
After kelp	2.27	3.98	1.76	3.12
Near coastline	1.37	2.19	0.98	1.87

Table 8.8: Significant wave height [m]

To evaluate the effect of the kelp forest, the dissipation by vegetation is shown in Figure 8.17. Again, the left plot gives the result during normal wave conditions (a) and the right plot during storm wave conditions (b). It is interesting to see the pattern of dissipation values in the plots. The lower left corner of the vegetation forest shows more dissipation by the vegetation compared to the rest of the forest even though the waves approach the forest from a different angle. This can be explained by the depth differences in the area.



(a) (b)

Figure 8.17: (a) Dissipation by vegetation for normal wave conditions $[m^2/s]$ (b) Dissipation by vegetation for storm wave conditions $[m^2/s]$

Finally, for each of the points the relative change in wave energy flux with and without the kelp forest is calculated and shown in Table 8.9. Before the kelp, the change in the energy flux is minimum, as there is no or little effect of the kelp. After the kelp, the reduction is increased towards a maximum, with the effect being higher during storm conditions. Near the coast, the effect of the kelp is almost dampened out and the change in wave energy flux is therefore approaching zero.

Data point	Run 2 *Normal conditions - Caleta*	Run 4 *Storm conditions - Caleta*	Run 2 *Normal conditions - 10 [°]*	Run 4 *Storm conditions - 10 [°]*
Before kelp	-0.46	-0.85	0	0
After kelp	-11.75	-19.81	-12.26	-21.16
Near coastline	-2.06	-2.43	-1.01	-1.79

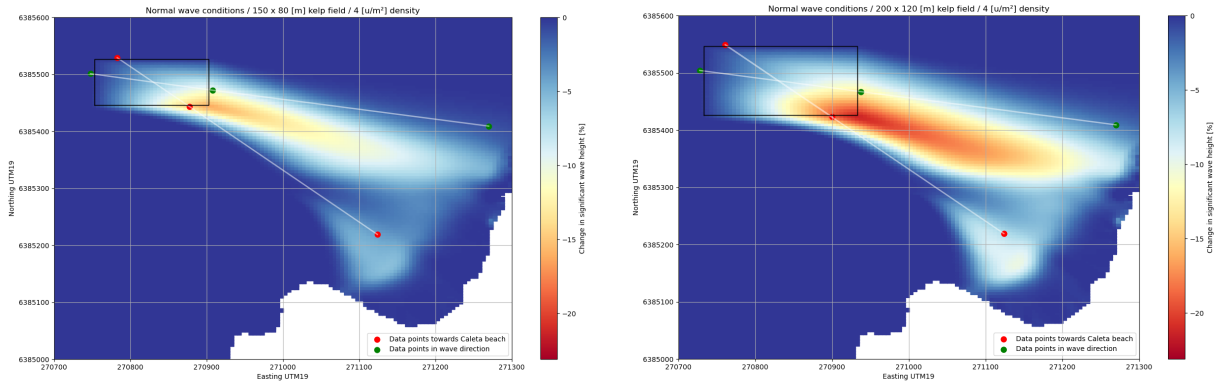
Table 8.9: Relative change in wave energy flux [%]

What can be concluded from the modelling of the field experiment is that the effect of the kelp forest increases during storm conditions. Also the dissipation by vegetation is strongly related to the water depth where deeper areas show less dissipation by vegetation. This is probably related to the fact it is not possible to vary the height of the kelp along the bathymetry, so a constant of 10 meters is used. Lastly, an important finding is the spreading of the relative change of the significant wave height towards the coast.

In the following two sections the possible next steps of the field experiment of Maitencillo will be discussed, namely whether it is convenient to increase the amount of the kelp plants per square meter and/or to increase the forest area. These are the parameters which are the most easily influenced by man, so these are interesting to change. The effect of changing it is compared to the case with normal wave conditions.

Enlarged kelp forest

The effect of increasing the area of the kelp forest is examined by running two more models, where the area size is multiplied with 4 and with 8. The result of the change in significant wave height for these two areas is shown in 8.18. In the plot, two things can be noticed visually when increasing the area: the value of change in significant wave height increases and the overall area of influence increases (from a value of -12 % and below). The parts with lower amount of change in significant wave height (until - 10 %) do not change a lot. Again, the most change in significant wave height starts at the right left corner of the kelp forest regardless of the size of the kelp forest.



(a) (b)

Figure 8.18: (a) Change in significant wave height for a 150 x 80 [m] kelp forest [%] (b) Change in significant wave height for a 200 x 120 [m] kelp forest [%]

Also for the enlarged kelp forest, the relative change in significant wave height and the relative change in energy flux are shown for each point in Tables 8.10 and 8.11.

Data point	Run 5 *150x80[m] - Caleta*	Run 6 *200x120[m] - Caleta*	Run 5 *150x80[m] - 10 [°]*	Run 6 *200x120[m] - 10 [°]*
Before kelp	0.00	0.00	0.00	0.00
After kelp	-3.23	-12.93	-7.15	-13.41
Near coastline	-4.17	-2.68	-1.15	-2.72

Table 8.10: Relative change in significant wave height at each point [%]

Data point	Run 5 *150x80[m] - Caleta*	Run 6 *200x120[m] - Caleta*	Run 5 *150x80[m] - 10 [°]*	Run 6 *200x120[m] - 10 [°]*
Before kelp	0.00	0.00	0.00	0.00
After kelp	-7.84	-24.20	-23.16	-33.48
Near coastline	-8.16	-5.37	-2.28	-5.37

Table 8.11: Relative change in wave energy flux [%]

Next, the effect of increasing the size of the kelp is determined by looking at the rate with which the reduction of wave height and wave energy flux increases for larger kelp forest sizes in the 10 [°] direction.

The effect of increasing the size of the kelp forest on the relative wave height reduction reduction is visible in Figure 8.20. The relevant length increase is the length increase of the part of the path of the 10

[°] wave that goes through the kelp forest, which is shown on the x-axis. A linear relation between the two variables, with a slope equal to the relative reduction during the run with the smallest path length, is added. This is done to help illustrate that the increase in reduction between each length increment is becoming smaller for larger path lengths.

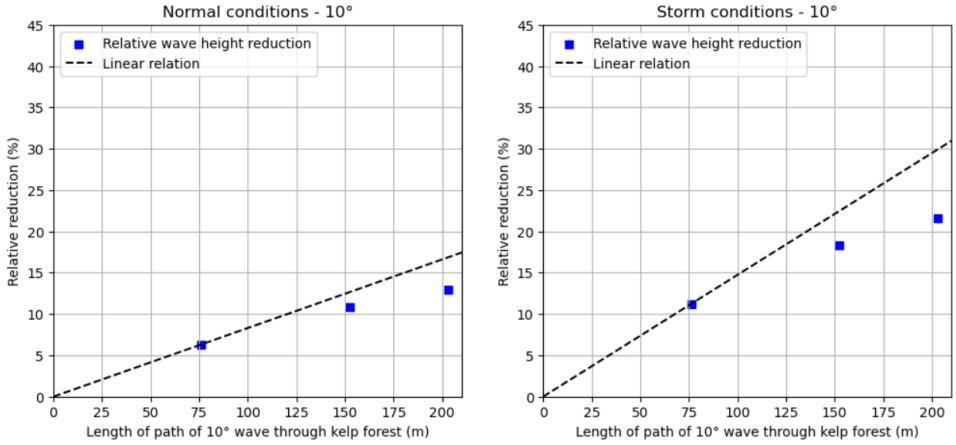


Figure 8.19: Relative reduction of wave height for changing forest sizes under different wave conditions [%]

The relation between the path length and and the relative reduction of wave energy is visible in Figure 8.19. Again, the increase in reduction becomes smaller when increasing the path length.

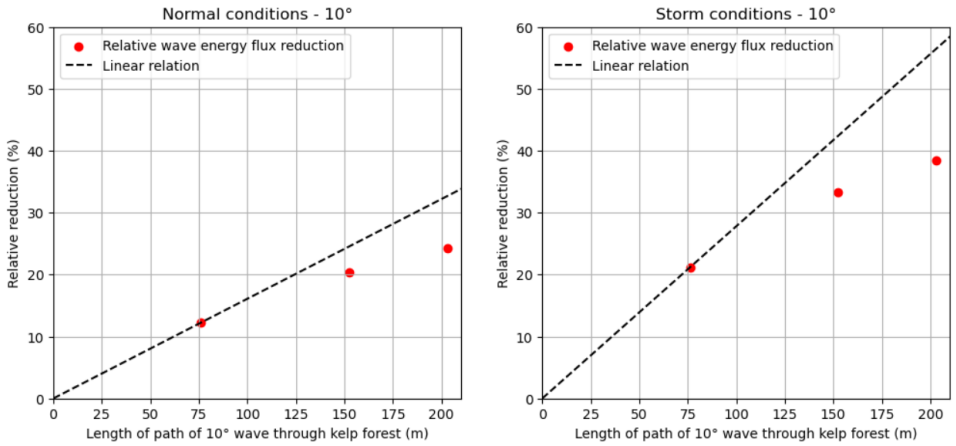
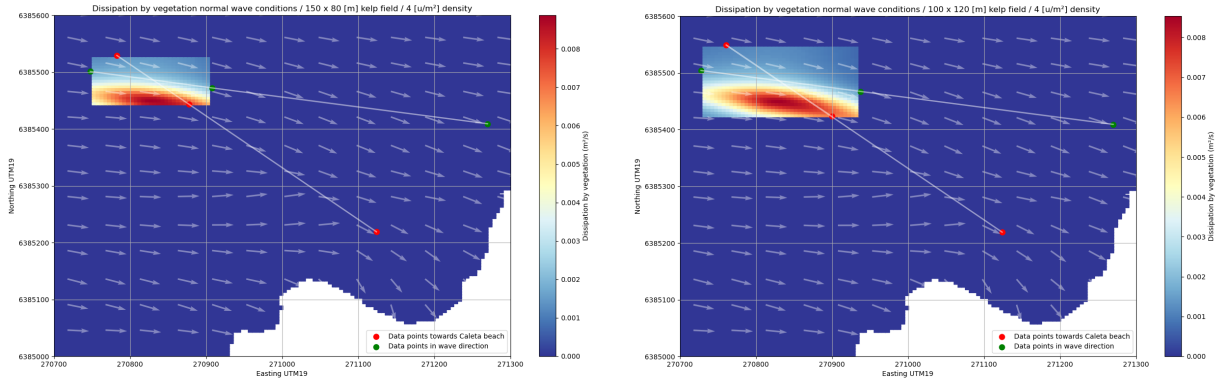


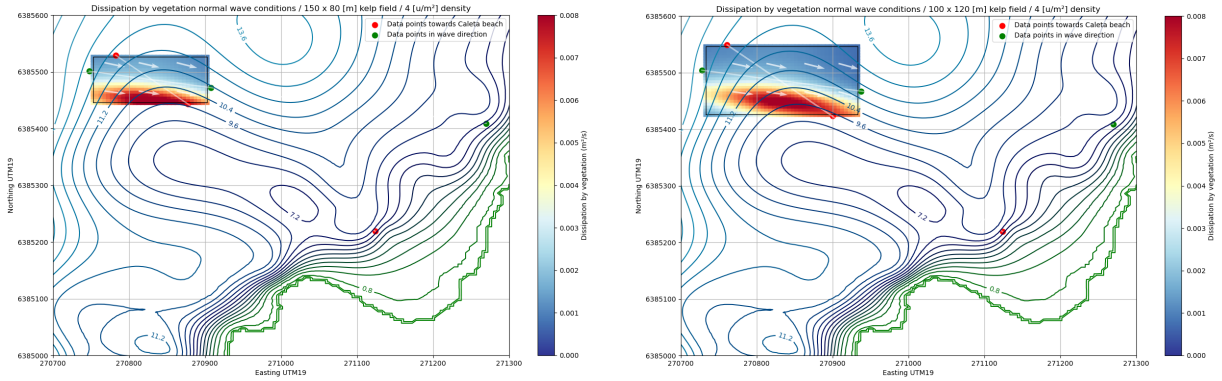
Figure 8.20: Relative reduction of wave energy flux for changing forest sizes under different wave conditions [%]

In the enlargement of the area of the kelp forest, it is interesting to look at the pattern the dissipation by vegetation shows. It would be expected that the most dissipation is where the waves enter the forest but the most dissipation is in the lower left corner. Figure 8.22 shows the relation of this dissipation by vegetation pattern with contour plots of the depth, shown in the second row of the figure. Here, we see that the dissipation is related to the waves entering the field and the amount of contour lines the waves passes. In the left corner, the waves pass a few contour lines almost perpendicular. In the upper part of the forest the waves penetrate in between these contour lines meaning there is almost no depth differences. This does make sense as the height of the kelp forest does not change over the kelp area meaning that changes in depth cause differences in dissipation.



(a) (b)

Figure 8.21: (a) Dissipation by vegetation [m^2/s] for a density of 8 [u/m²] (b) Dissipation by vegetation [m^2/s] for a density of 16 [u/m²]

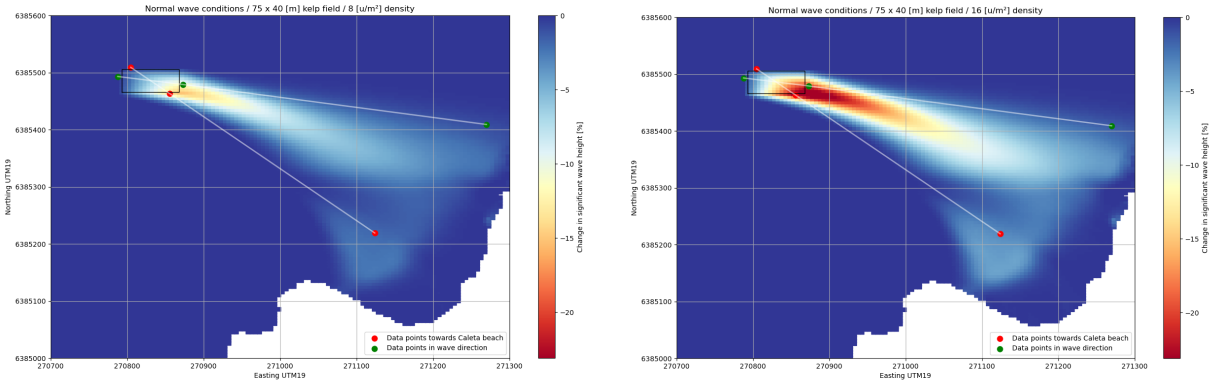


(a) (b)

Figure 8.22: (a) Dissipation by vegetation [m^2/s] for a density of 8 [u/m²] (b) Dissipation by vegetation [m^2/s] for a density of 16 [u/m²]

Increased density

In the following part the density is increased during normal wave conditions and a kelp forest size of 75 x 40 m. The hydraulic efficiency is shown for the case of a density of 8 [u/m²] and 16 [u/m²] in Figure 8.23. What can be observed from the plots is that the change in significant wave height increases from a maximum of -14 to a maximum of -21 but the shape is somewhat the same.



(a) (b)

Figure 8.23: (a) Change in significant wave height [%] for a density of 8 [u/m²] (b) Change in significant wave height [%] for a density of 16 [u/m²]

Also for the increased density of kelp forest, the relative change in significant wave height and the relative change in energy flux are shown for each point in Tables 8.12 and 8.13.

Data point	Run 9 *8 [u/m²] - Caleta*	Run 10 *16 [u/m²] - Caleta*	Run 9 *8 [u/m²] - 10 [°]*	Run 10 *16 [u/m²] - 10 [°]*
Before kelp	-0.46	-0.89	0	0
After kelp	-11.32	-20.02	-11.90	-21.27
Near coastline	-1.91	-3.30	-0.92	-1.53

Table 8.12: Relative change in significant wave height [%]

Data point	Run 9 *8 [u/m²] - Caleta*	Run 10 *16 [u/m²] - Caleta*	Run 9 *8 [u/m²] - 10 [°]*	Run 10 *16 [u/m²] - 10 [°]*
Before kelp	-0.91	-1.78	0	0
After kelp	-21.37	-36.03	-22.39	-38.02
Near coastline	-3.78	-6.49	-1.83	-3.04

Table 8.13: Relative change in wave energy flux [%]

The effectiveness of increasing the kelp density is checked in the same way as has been done for the kelp forest size. Figure 8.24 and Figure 8.25 show the effect of increasing the kelp density on the relative wave height reduction and the relative wave energy flux reduction respectively. Both of the studied quantities increase when increasing the kelp density, but this increase becomes smaller each step when the density increases.

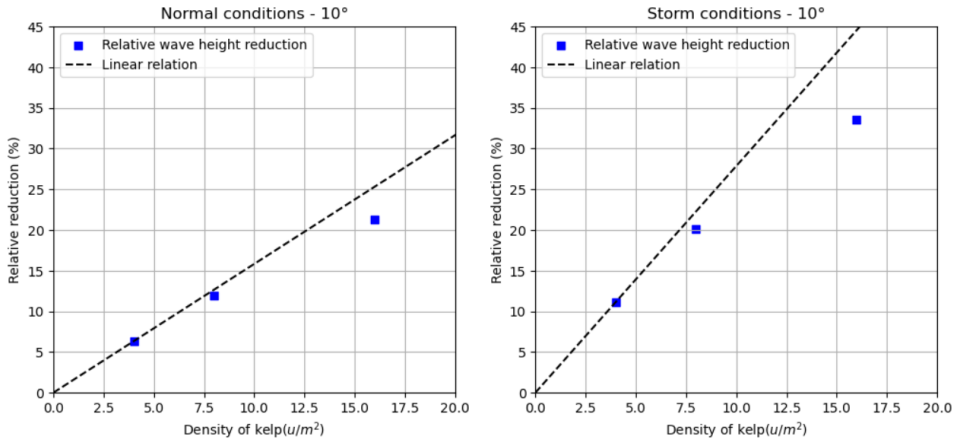


Figure 8.24: Relative reduction of wave height for changing kelp densities under different wave conditions [%]

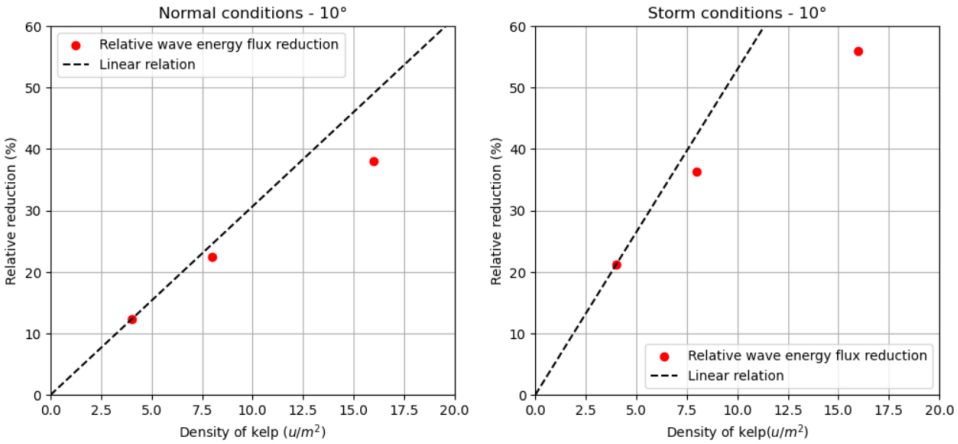
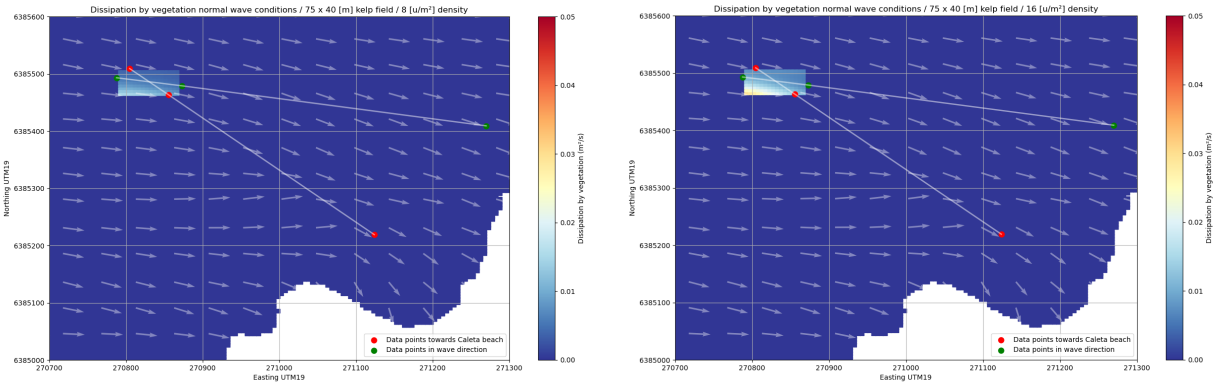


Figure 8.25: Relative reduction of wave energy flux for changing kelp densities under different wave conditions [%]

Lastly, the dissipation by vegetation is shown in Figure 8.26.



(a) (b)

Figure 8.26: (a) Dissipation by vegetation [m^2/s] for a density of 8 [u/m²] (b) Dissipation by vegetation [m^2/s] for a density of 16 [u/m²]

Variance density spectra

For each run and data point, energy is calculated, resulting in multiple spectra. These Variance Density Spectra (VDS), otherwise known as Directional Wave Spectra (DWS), are three dimensional. Their energy is dependent on frequency and direction: $E(f, \theta)$. They are presented in two ways: (1) as the original Directional Wave Spectrum and (2) as an Dimensional Variance Density Spectrum integrated over all directions, showing energy across frequencies. All spectra are presented in Appendix J, with key cases shown here.

When comparing the different DWS in Figure 8.27 it is immediately evident that there is an unusually large increase in total energy between the first and second points on the Caleta line. The total energy is calculated by integrating twice, once over the frequency bins and once over the directional bins. The energy most likely differs due to shoaling and refraction, since energy scales with wave height according to:

$$E = 1/8\rho g H^2$$

. As the Caleta line is not in the direction of the waves, the amount of energy in the DWS cannot be compared for these points. The same holds for directional spreading which is, due to this error, mostly based on the bathymetry.

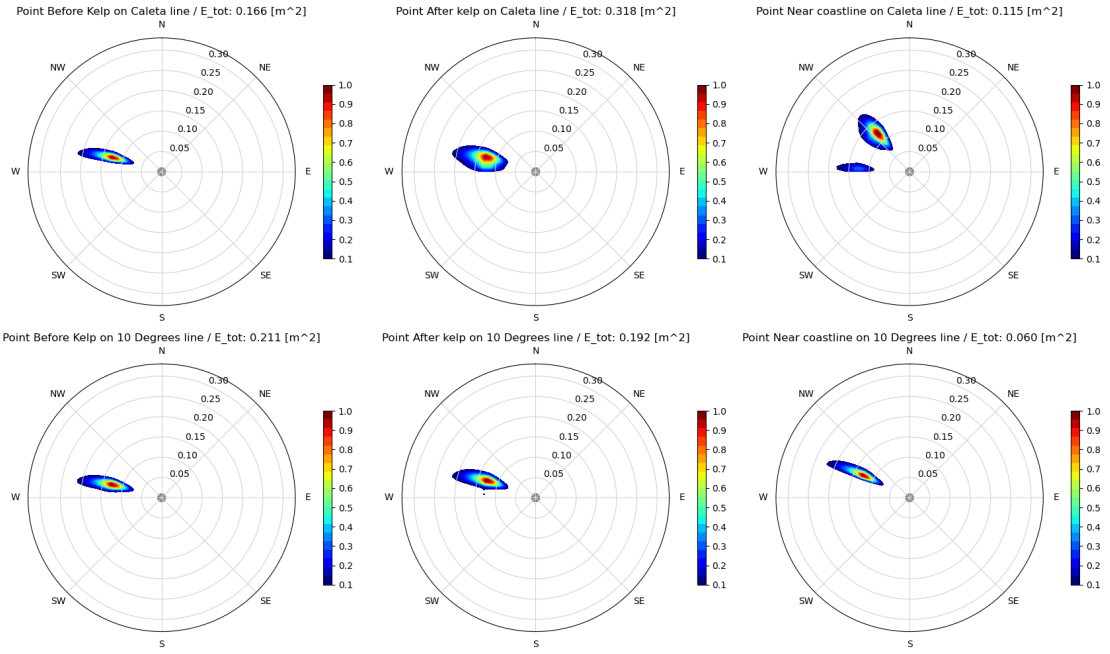


Figure 8.27: DWS of run 2: 75x40 - normal wave conditions - 4 $[u/m^2]$

For further examination of the VDS only the reduction of energy in percentage (RoE), between each run for one specific point is discussed, in order to filter out the effect of the bathymetry. In the upcomming RoE figures it is assumed that the data between 1/30 [Hz] and 1/20 [Hz] is not reliable because of the unexpected patterns.

The difference in energy between no kelp forest present (run 1) and the prototype present (run 2) for both the Caleta line and the 10 degree line is covered first. Figure 8.28 clearly shows that there is more energy reduction for higher frequency waves in point 2 on both lines. Under storm conditions the lines look very similar however the amount of reduction is twice as much, this is because variance scales with squared wave height. Interestingly, the effect of the kelp forest seems to have dampened out for long waves on the Angle line, while short waves still experience an effect.

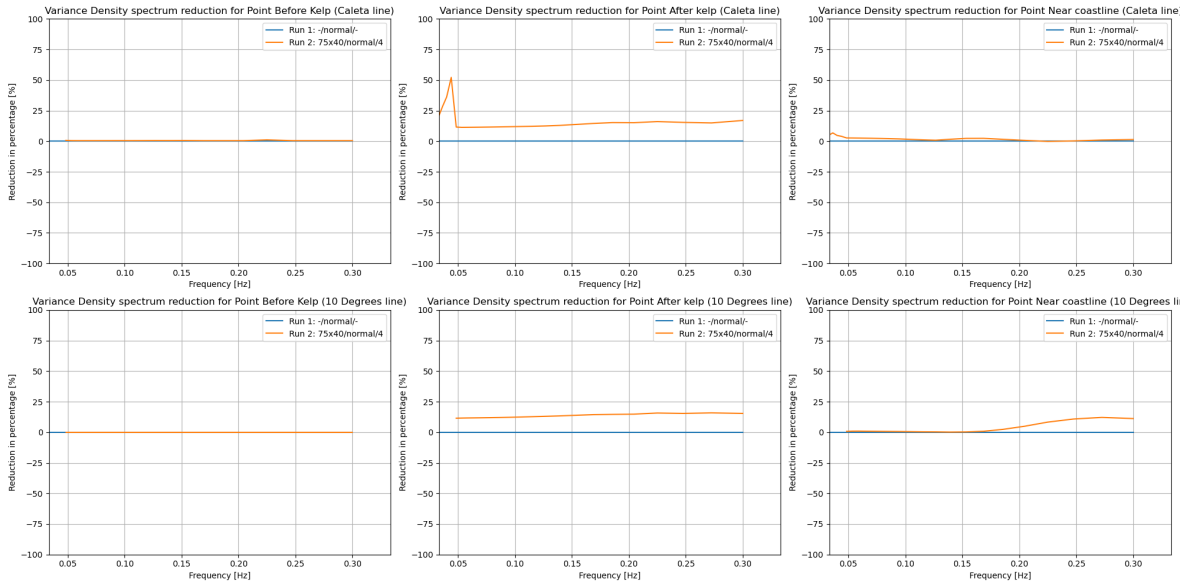


Figure 8.28: Reduction of energy [%] when comparing run 1 and run 2

Next, the RoE when increasing density is discussed. As can be seen in Figure 8.29, again, the third point on the Angle line still shows a strong reduction for the shorter waves. When the density increases, point 3 on the Caleta line also shows reduction of energy but more towards the longer waves than the shorter waves. The reason for a peak reduction around the specific frequencies 0.05 [Hz] and 0.17 [Hz] is not clear. In point 2, the energy reduces with increasing density. The jump between run 2 and run 9 is less then between run 9 and run 10. This is different for storm conditions shown in Figure 8.30. Under storm conditions the increase between run 3 and run 4 is very big and further increase of the density shows steady energy reduction. With every increase, the amount of energy reduction is the same. Furthermore, a difference in energy reduction pattern between point 2 on the Caleta line and point 2 on the Angle line is visible. While the energy reduction for higher frequencies is almost the same, the energy reduces slightly more for lower frequencies on the Angle line. This is probably because the waves travel longer through the kelp forest when following the Angle line compared to the Caleta line.

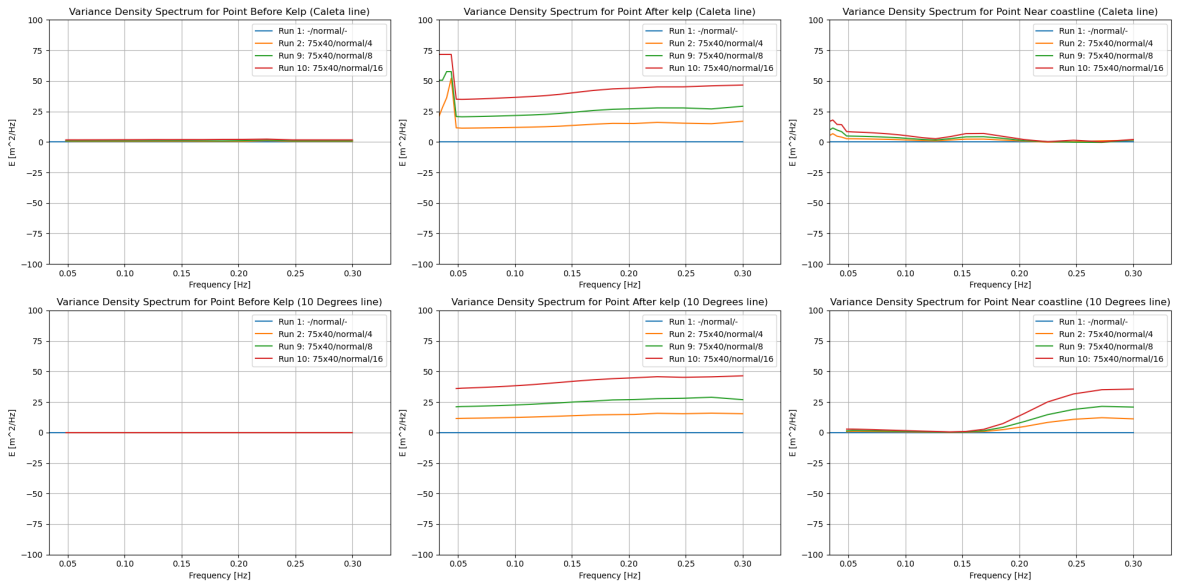


Figure 8.29: Reduction of energy [%] when increasing density under normal conditions

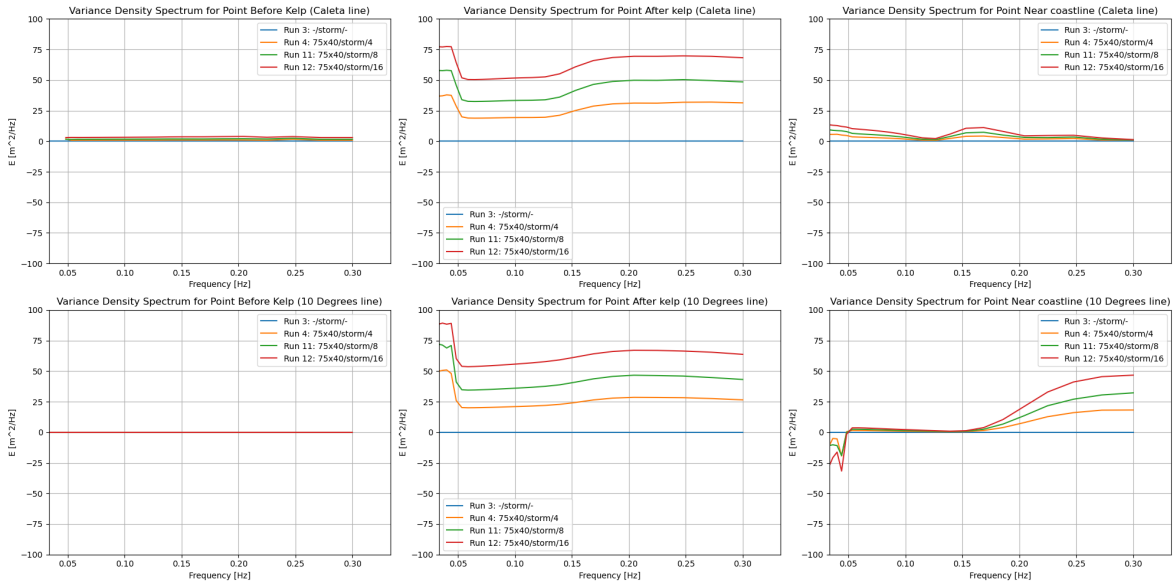


Figure 8.30: Reduction of energy [%] when increasing density under storm conditions

Lastly, the reduction of energy by increasing the area is discussed. These reductions are shown in figures 8.31 and 8.32. Right away it can be noticed that for a kelp forest size of 200x120, the amount of reduction in point 1 and 2 on the Caleta line is not as expected. Since the bathymetry has been filtered out, the difference in energy can only be caused by the kelp forest, but there should not be a reduction of energy due to the kelp forest before the waves have past the kelp forest. Because of these unexpected results from runs 6 and runs 8 in points 1 and 2 on the Caleta line, the Caleta line is not further discussed here.

The Energy reduction in the Angle line does show reliable and interesting results. By increasing the area more, the extra effect of the kelp forest on the energy becomes less. Again, there is more reduction of energy in shorter waves than longer waves but the difference in the amount of reduction is smaller. In point 3 on the Angle line there is again preliminary a reduction in higher frequencies. However, in comparison to the energy reduction when increasing the density, there is now also some reduction for the longer waves. This is very interesting. Increasing the area clearly has significantly more effect on reducing the longer waves then increasing the density.

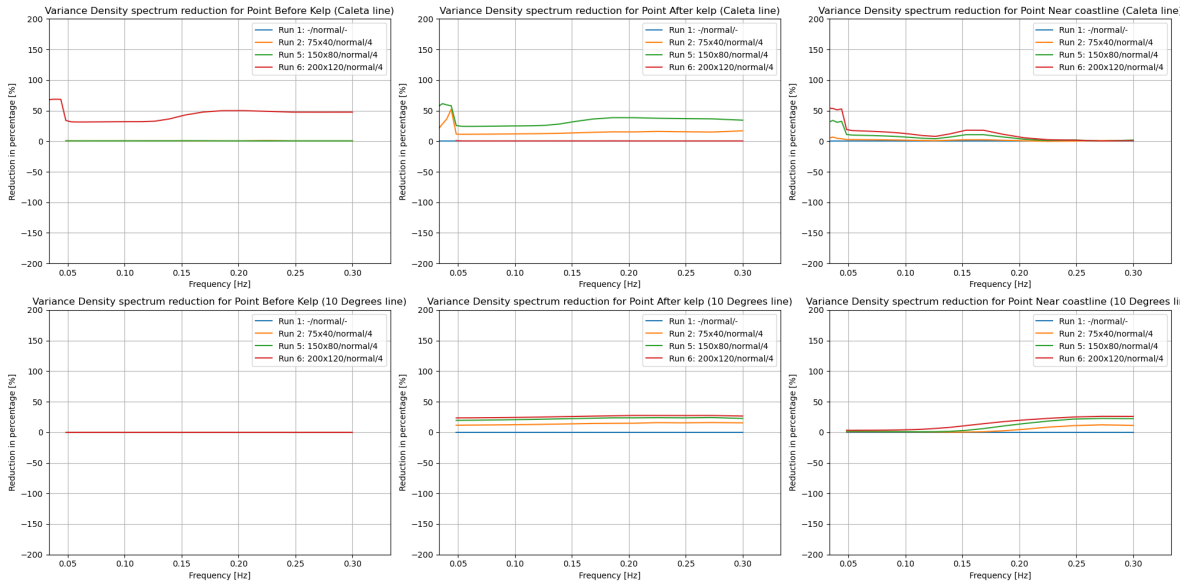


Figure 8.31: Reduction of energy [%] when increasing forest area under normal conditions

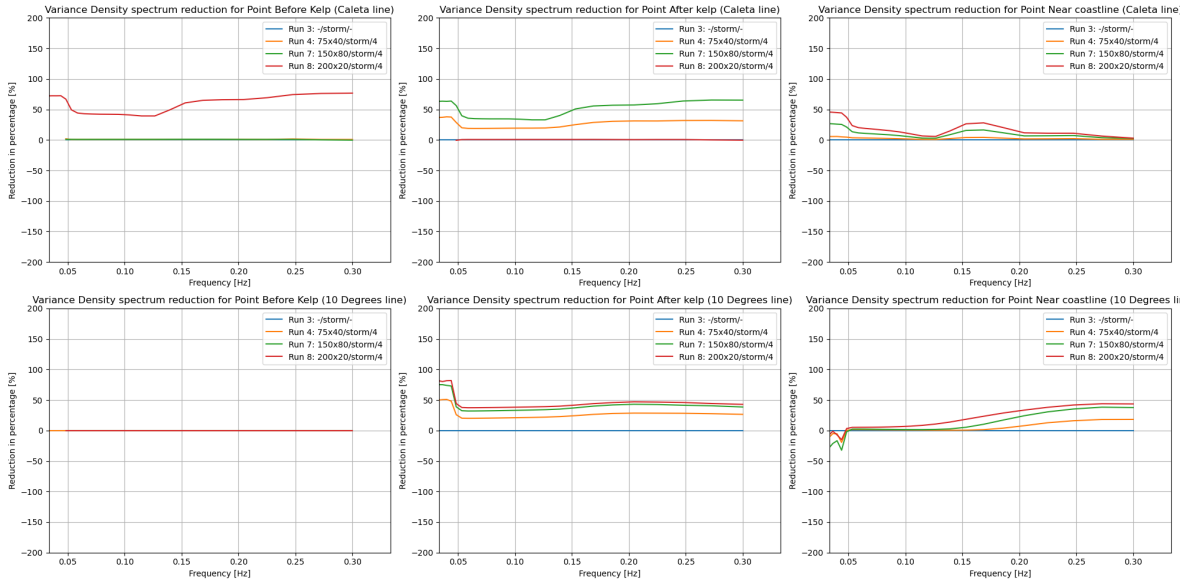


Figure 8.32: Reduction of energy [%] when increasing forest area under storm conditions

8.7. Conclusion

To be able to answer the main research question, the sub-questions regarding the specific parameters are addressed and answered first:

- What is the effect of the prototype kelp forest, that is currently being applied?

The prototype kelp forest decreases the wave height in Caleta direction and 10 [°] direction by 6.06% and 6.33% respectively. This is smaller than the expected range of 10-20%. Under storm conditions however, bigger reductions are obtained that are around the lower end of the mentioned range. The wave energy flux reductions in Caleta direction and 10 [°] direction are 11.75% and 12.26% respectively. The fact that these reductions are larger than the wave height reductions is in line with the expectations. The changes in significant wave height and wave energy flux are largest just behind the kelp forest in

the direction of the waves and spread out when approaching the coast. The dissipation by vegetation is the most in the kelp forest area where the water depth is the smallest. From the difference in variance density spectra between the situations with and without vegetation and thus the reduction of variance in percentage over all frequencies, it can be concluded that the prototype kelp forest has more wave attenuation for shorter waves than longer waves right after the forest.

- What is the effect of increasing the size of the kelp forest?

When increasing the kelp forest size, the effectiveness of the increase becomes smaller the more you increase it. This is in line with the hypothesis that stated: "Increasing the size of the kelp forest will eventually lose its efficiency as the waves dampen out". The variance density spectrum shows that increasing the area's size has relatively more effect on low frequency waves compared to high frequency waves in point 3 of the Angle line.

- What is the effect of increasing the density of the kelp forest?

When increasing the density, the reduction of the wave height and wave energy flux initially increases almost linearly, but the increases diminishes as the density increases, just like for the forest size increase. When comparing the effect of increasing the density to the effect of increasing area size, the effect of the kelp density is larger. Under storm conditions the effect of increasing the density is twice as much over all frequencies. The density increase primarily has an effect on the high-frequency waves.

- What is the effect of the position of the kelp forest with respect to the wave angle?

From the 2D results it can be seen that the effect of the kelp forest is largest in the 10 [°] direction. Right behind the kelp forest this does not play a big role yet, as the points right behind the kelp forest have practically the same amount of reduction in wave height and wave energy. However, towards Caleta beach the effect of the kelp forest dampens out much quicker than in the 10 [°] when the waves travel further onshore. The coast that is aligned under the 10 [°] angle with the kelp forest is thus best protected.

The main research question is:

"What is the effect of kelp forest characteristics on the wave height, the wave energy flux and the energy density spectra, under different wave conditions?"

Increased kelp forest area and density both lead to more wave attenuation, with the density having relatively more effect on the efficiency of the kelp. Furthermore, the effect of the kelp forest is biggest under storm conditions. This is a very positive conclusion, as the extreme wave events are the events that are mainly responsible for coastal erosion, as concluded in Chapter 3.

Additionally, because of directional spreading the effect of the kelp forest dampens out when the waves travel further onshore and therefore the overall effect reduces. All things considered, this suggests that optimizing the positioning, density and size of the kelp forest, can enhance their natural wave-dampening effects, especially in extreme weather scenarios.

9

Scale-up analysis of the kelp forest project

The kelp project started almost two years ago and they are currently planting the first section of the artificial kelp forest, which measures 75 meters by 40 meters. Although the project is far from finished, it is crucial for the team to start applying for permits for new initiatives now to ensure continuity, as the fishermen and aquaculture agency have about a year to approve them. With the two-year, $200,000 funding from the Research and Development Department of the Central Government nearing completion, securing new funds for scale-up projects becomes the top priority to maintain ongoing progress.

The first up-scaling project in Maitencillo is making the kelp forest bigger, this may be a solution to protect the whole bay. Another scale-up project is expanding aquaculture to include new species, not just planting seaweed, but also creating habitats where mussels and oysters can live. This will benefit the fishermen, who are the legal owners of the kelp forest. Lastly, a scale-up opportunity is to expand the project to other areas along the Chilean coastline, facing issues with coastal erosion.

Scaling up is essential for effectively mitigating coastal erosion, enhancing biodiversity, and addressing these challenges on a larger scale. Expanding the kelp forest is necessary to understand how it interacts with larger waves and to accurately measure its energy dissipation. To fully comprehend the impact of artificial kelp forests, it's important to test their effects in different bays under varying conditions such as wave height, currents, and kelp forest depth. This will provide valuable insights into how the kelp forest performs in diverse environments before broader expansion and large-scale application of the solution. This chapter will discuss opportunities and threats on upscaling the project.

9.1. Opportunities for scaling-up

Upscaling the kelp project could bring a range of environmental, economic, social, and cultural benefits. These are described in the sections below.

9.1.1. Environmental benefits

The primary environmental benefit of the artificial kelp forest, and the main reason for this project, is that a vegetated foreshore can potentially reduce the impact of storm surges. Algae growing near the shore could possibly help prevent beach erosion by dissipating wave energy through depth-induced wave breaking, bottom friction, and wave attenuation, thereby creating a more stable foreshore (Section 5.1)

The second environmental benefit is that the kelp forest will enhance biodiversity and improve the habitat for marine animals. Kelp forests are the most productive ecosystems in the world, providing refuge, spawning grounds and food for a diverse range of invertebrates and fish, which stimulates reproduction (Section 5.1). In addition, the fish that do not live in the kelp will benefit from the animals that grow in the kelp as a source of food (Fisheries, 2024a).

Another effect of the kelp forest could be reducing the fishing pressure. As currently 28.8% of global fish stocks are estimated to be overfished or fished at a biologically unsustainable level. (Food & of the United Nations, 2024)

Additionally, it plays a crucial role in slowing down ocean deoxygenation and acidification by performing photosynthesis (Section 5.1). Kelp is a powerful force in storing this persistent greenhouse

gas, absorbing an estimated 20 times more carbon dioxide per acre than terrestrial forests and mitigating the effects of climate change. (Browning & Lyons, 2020). On a global scale, kelp forests would therefore sequester between 14 and 292 megatonnes of carbon over 30 years. In addition to carbon, kelp could also be a source of nitrogen and phosphorus removal from the ocean. (Eger et al., 2023).

9.1.2. Social and cultural benefits

Social and cultural benefits The social and cultural benefits of the upscale of the project are mostly related to the current disappearance of the beaches due to coastal erosion. Through the open questions of the assessed survey, local stakeholders had the opportunity to express their concerns on the coastal erosion threats which result in the disappearance of their local beaches. Respondents expressed their different viewpoints on the coastal erosion matter and how it affects their personal living or working experience. Here, it was noticeable that some respondents have a sense of anxiety towards the disappearance of coastal areas and beaches. One example is the following statement of a respondent: “In the past, there were no beach reductions like this, now, I am worried that they will fully disappear. I am afraid that that day will come and that my grandchildren cannot enjoy the beaches anymore” Thus, a feeling of worrisome towards the disappearance of the beaches is present amongst local stakeholders.

Nevertheless, not only does the disappearance of beaches lead to anxiety, also the result that water is moving inland and coming closer to the building structures causes stress. In this regard, an example of a respondent which expresses their concerns is: “If you see the coastal erosion in the majority of our beaches in Maitencillo, living very close to the sea is worrisome. The water is coming closer towards our houses.”. Overall, it can be noted that a sense of anxiety is caused by coastal erosion in the surroundings of the local stakeholders. Here, the upscale of the project could make sure that these local stakeholders see that measures are taken to mitigate these issues. Research conducted by Abu et al. (2024) shows that interventions that mitigate risk influence social behavior positively and results in less anxiety.

Not only would the upscale of the project lead to a reduced anxiety level of inhabitants in coastal areas by protecting them, it could potentially also lead to revitalization of coastal areas (Magnere, 2024). The disappearance of Chilean beaches results in a less appealing coastal area due to the lack of places to enjoy a beach day. Meaning that there are less sandy beaches and more rocky areas alongside the shoreline. Also does this result in the decrease of opportunities for water sports such as surfing or swimming. Furthermore, respondents also expressed their concerns in this regard, here an example of a statement of a respondent is: “ I experience that a reduced surface for swimmers and surfers is left and that the coastal infrastructure is exposed. Without the beach, there are less tourists. Also this now results in an increase of stones and rocks that are uncovered.” Therefore, if the beaches in these coastal areas could be revitalized by the expansion of the project, it could result in moving towards a situation where the beaches are a prominent part of the coastal areas in Chile again. This would result in the return of the big beach culture and thus result in a more appealing living and working situation as well as in the attraction of tourists.

Overall, the expansion of the kelp forest project to other areas could potentially result in different social and cultural benefits. Firstly, it could lead to a decreased level of anxiety among local stakeholders regarding the disappearance of the beaches and the water moving inland. Also, the kelp forest project could be an opportunity to revitalize the beach culture that used to be more prominent in Chilean coasts. This could be managed by the restoring of sandy beaches and creating more water sport opportunities. Eventually resulting in a more appealing area for residency, work and tourism.

9.1.3. Economic opportunities

Artificial kelp forests offer substantial economic opportunities, contributing to the growth of local industries, improving marine biodiversity, and enhancing ecosystem services. This chapter outlines the economic benefits of an artificial kelp forest through its impact on fisheries, nutrient cycling, and carbon sequestration, as well as the total estimated economic value of these services.

Firstly, the creation and maintenance of artificial kelp forests would create jobs for local communities in the cultivation, harvesting and processing of kelp. These jobs would range from manual labor to technical positions, such as monitoring kelp growth and maintaining the structures. The kelp forest

could also stimulate marine research. There would likely be an increased demand for skilled scientists, marine biologists and oceanographers to study the impact of artificial kelp forests on marine biodiversity and carbon sequestration, for example.

Second, kelp forests play a crucial role in supporting fisheries, providing habitat and food for many commercially valuable species. An artificial kelp forest can boost fishery production, a study in Australia estimated the economic values of up to $29,000 per hectare per year. This contribution comes from the improved health of marine ecosystems, which supports a variety of species, including lobster, abalone, crabs, and fish. Among these species, abalone and lobster often represent the highest economic returns, making up more than 25% of the total fishery value in some areas (Eger et al., 2023).

In addition to supporting jobs in commercial fishing, artificial kelp forests will also boost recreational fishing and contribute to the ecotourism sector (Programme, 2023). These forests attract tourists interested in marine wildlife, snorkeling, diving, and other eco-tourism activities like kayaking, bird watching, and marine mammal watching. This creates opportunities for tour operators, dive instructors, and local hospitality industries, including hotels, restaurants, and transportation services (PISCO, n.d.) . The expansion of beaches due to kelp forests also enhances their value, further benefiting tourism (Winckler et al., 2023).

Kelp forests are effective in removing harmful nutrients from the water and sequestering carbon, providing critical ecosystem services that also have economic implications. The combined economic value of carbon sequestration, nitrogen, and phosphorus removal from artificial kelp forests amounts to $72,020 per hectare annually, according to an Australian study led by UNSW Sydney.

The Macrocystis Kelp forests capture significant amounts of carbon from the atmosphere, with a sequestration rate of 101 grams of carbon per square meter annually. However, the economic value of carbon sequestration is relatively low, at $163 per hectare per year, due to the currently low market price of carbon. Despite this, the role of kelp forests in climate change mitigation through carbon capture is vital, especially as the demand for carbon credits rises globally.

Nitrogen removal is one of the most economically valuable services provided by kelp forests. Artificial kelp forests can remove 657 kilograms of nitrogen per hectare annually, which is crucial for maintaining water quality and preventing harmful algal blooms. The economic value of nitrogen removal is estimated at $73,831 per hectare per year, making it the most significant ecological service provided by artificial kelp forests.

Although phosphorus removal provides less economic value than carbon and nitrogen, it remains an essential service. Kelp forests can remove 59 kilograms of phosphorus per hectare annually, with an economic value of $4,075 per hectare per year. Phosphorus removal helps maintain the ecological balance in coastal waters, preventing eutrophication and supporting the overall health of marine ecosystems (Eger et al., 2023).

Finally, the artificial kelp forest will offer economic benefits by protecting the coast. By dissipating wave energy, these forests reduce storm surges and beach erosion, which in turn helps safeguard coastal infrastructure and prevent property damage. This protection reduces the need for costly property defenses or replacements, providing significant indirect economic savings (Fisheries, 2024b).

To conclude, the total economic benefits of an artificial kelp forest come from a combination of extra jobs, fisheries enhancement, tourism boost, carbon sequestration, nitrogen and phosphorus removal and coastal protection. The average combined value per hectare for only the fisheries, carbon sequestration and nutrients removal ranges from $38,799 to $165,200 annually, depending on the region and the species of kelp. Globally, kelp forests are estimated to contribute $500 billion annually to the economy, with a net present value of $7.44 trillion over the next 20 years. This estimate does not even include tourism, coastal protection and the job creation, which could further increase the overall value of kelp forests (Eger et al., 2023).

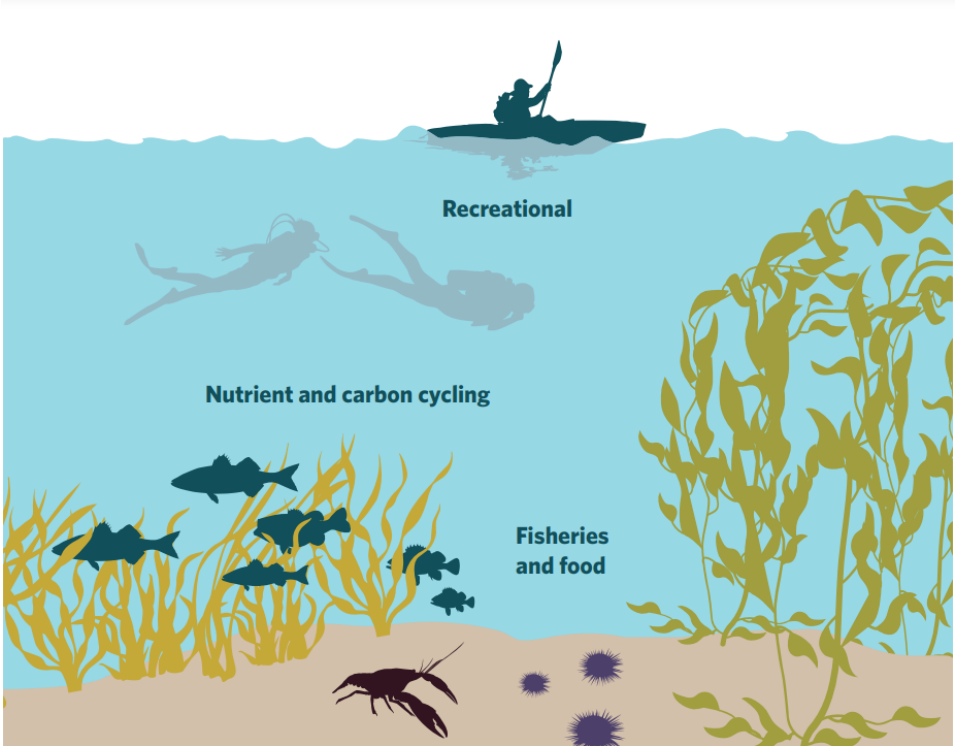


Figure 9.1: Ecosystem benefits illustrated by Jon Ferland

9.2. Threats and challenges with scaling-up

Scaling up the project also brings certain challenges, including environmental, economic, social, and political risks, which are outlined below.

9.2.1. Environmental risks

The primary environmental risk is the sudden disappearance of the planted kelp forest, which could occur for various reasons. As outlined in Chapter 5.1, the specific kelp species used in this research is Macrocystis pyrifera, or giant kelp — the only type used in the project. Magnere mentioned in the interview that one significant environmental threat is predation (*Interview with Milton Magnere*, 2024). Several species feed on Macrocystis pyrifera, including sea urchins, northern kelp crabs, and turban snails. Typically, sea urchins feed on kelp pieces that settle on the seafloor, but during population surges, they also consume the stipes and holdfasts, which can destroy entire kelp forests. (*SIMON :: Species Database*, n.d.). Since sea urchins are present at the experimental site in Maitencillo, insufficient monitoring could lead to rapid deforestation of large sections of the kelp in a short period (Perreault, Borgeaud, & Gaymer, 2014).

Another very important threat is the harvesting of kelp, in which the Macrocystis pyrifera type is popular (Camus, Infante, & Buschmann, 2018). Globally, over one million tons of wild kelp are harvested annually, with around 40% coming from Chilean coasts, highlighting the scale of the issue. The harvested seaweed is sold to commercial markets, primarily in China, for use in food production, pharmaceuticals, and textiles. This large volume of harvesting in Chile is largely due to the lack of regulations and the absence of an up-to-date kelp inventory. Hamilton, a postdoctoral researcher at the University of California, notes that monitoring efforts in Chile are often inconsistent, largely because of the complex mix of management regimes involved. (Scherer, 2022). Additionally, the challenging geography and limited access to the coast make effective oversight by the SERNAPESCA nearly impossible (Vásquez, Morales, & Vallone, 2024). Without clear and strict regulations in place, the newly planted kelp forest could be at risk of being harvested and removed again. When the harvesting continues at the current rate, most of Chile's remaining kelp forests will fully disappear in the next 10 years (Verutes, 2024). Consequently, new policies are needed to preserve the kelp forests.

Lastly, the placement of a kelp forest might negatively influence its environment due to (unintended)

ecosystem alterations. Such changes include light availability, nutrient levels, disruption of benthic organisms, and spread of parasites. Accordingly, a targeted monitoring effort is necessary when scaling up the kelp forest field. (Bhuyan, 2023).

9.2.2. Economic risks

The main economic risk in Chile is the economic dependence on harvesting kelp. In Northern Chile alone, more than 11,000 people depend directly or indirectly on the collection and harvesting of this resource. The total current economic value of the kelp industry in Chile is estimated to be US$409,527,000. (Vásquez et al., 2013). The international demand for Chilean kelp is still growing; annually they produce 390,000 dry tons, which accounts for more than US$100 million in return (Vásquez et al., 2024). These economic benefits make establishing regulations for kelp harvesting a lower priority.

Furthermore, the economic advantages associated with kelp make it vulnerable to illegal harvesting for several reasons. First, the kelp can be easily detached from the rocks. Second, the limited oversight by the SERNAPESCA enables unlawful harvesting. Lastly, for unemployed immigrants, illegal kelp harvesting presents an attractive income opportunity, as it is one of the few available options. (Vásquez et al., 2024). Thus, even with the introduction of regulations, the threat of illegal harvesting is likely to persist.

Finally, the risk of losing the investment remains significant, as the project is still in its experimental phase. Up until now, the central government has contributed US$200,000, with the potential for an additional US$800,000 from the regional government of Valparaíso. This is a substantial amount for a country also struggling with other pressing environmental concerns. Despite Chile's relatively strong economy in Latin America, it continues to struggle with inequality, where social gaps remain high. (Department, 2024). As a result, the high investment costs might not be fully recovered if the project doesn't achieve its anticipated outcomes. Moreover, this highlights the project's dependency on external funding, creating the risk of insufficient financial support for its expansion. Furthermore, changes in policy or economic conditions could lead to reduced funding and could make scaling up the project more challenging. Thereby, companies like GNL and Puerto Ventanas cannot give any certainty of cooperation either, so the project cannot rely on their involvement.

9.2.3. Social challenges

Expanding the kelp project presents several social challenges. As highlighted in Chapter 7, a project of this scale requires the involvement of numerous stakeholders. One of the biggest challenges lies with the fishermen's associations, which are key to launching and expanding the project in new areas since they legally own the coastal regions and oversee aquaculture activities. However, these associations tend to be cautious about engaging in research projects due to negative past experiences. Historically, fishermen were more willing to participate, but many of these initiatives were poorly executed despite being well-funded (*Interview with Fishermen's Federation of Quintero*, 2024). In some cases even, initiators took a large share of the funds for themselves, which led to distrust among the associations. As a result, they now insist on being financially compensated before agreeing to collaborate.

Local residents may also pose a challenge. If they aren't sufficiently aware of the serious problems coastal erosion can cause, it is unlikely to become a priority on the political agenda of municipalities. This is especially evident near election time. In the conversation with the mayor of Puchuncaví, it became clear that his focus was mainly on issues residents deemed important, and currently, coastal erosion was not one of them (*Interview with Marcos Morales Ureta*, 2024). Therefore, it is crucial to inform and engage local residents. The potential strategies outlined in Chapter 6.6 should be employed to ensure they understand the benefits of the kelp project. Without sufficient education, residents may be skeptical, particularly if they are more concerned with immediate issues like air pollution.

Lastly, the kelp project could potentially negatively impact tourism and recreational activities due to several aspects which may not sit well with local business owners. Research by the United Nations Environment Programme (2023) suggests that kelp forests can be perceived as intimidating, with people often associating them with large, dark shapes underwater. This potential perception could reduce the popularity of activities like diving, surfing, fishing, and swimming, potentially leading to a decline in tourism in areas where kelp forests are established. As a result, local business owners who rely on these activities may resist the project.

9.2.4. Political and regulatory challenges

When scaling up the project, navigating Chile's complex regulatory framework will become essential. One significant hurdle is that, once the project moves beyond its experimental phase, permits may no longer be arranged through fishermen but instead require approval from the Chilean Armed Forces. This shift could introduce substantial delays, as permits for large-scale aquaculture farming can take up to 10 years to process (*Interview with Milton Magnere*, 2024). Additionally, the project must comply with overlapping environmental regulations, coastal management policies, and aquaculture laws, with governmental bodies such as the Environmental Assessment Service (SEA) adding further layers of bureaucracy. As the project grows, the research team must start paying attention to these complicated laws and regulations. This requires a shift from mainly informal discussions with fishermen and municipalities to a more formal, professional approach, which could lead to additional delays.

Political challenges could also emerge as the project scales up. Currently, the project is funded by the central government through the Ministry of Science, with potential additional support from the regional government of Valparaíso and local municipalities. However, communication so far has only involved individual contacts rather than informing the full institutions. (*Interview with Milton Magnere*, 2024). This creates a risk that, with upcoming elections, new officials or parties could come to power, requiring negotiations to start from scratch and causing delays. Additionally, coastal erosion may struggle to compete with more immediate environmental concerns, such as air and water pollution, particularly in regions like Quintero Bay, where industrial pollution is a major issue (*Interview with Maria Martinez*, 2024). Politicians, especially during election periods, may prioritize issues with greater public support, leaving the kelp forest project with limited political support (*Interview with Marcos Morales Ureta*, 2024).

9.3. Potential collaborations and partnerships

To successfully scale up the kelp project, diverse collaborations are essential. Partnerships with local communities, governmental bodies, the private sector, and research institutions each offer unique benefits and play critical roles in the project's development. Which collaborations might be interesting for scaling up the project have been written down below.

9.3.1. Local community

Collaborations with the local community are crucial in order to gain local support. Not only are these collaborations important to gain support, local stakeholders are also important in terms of resources and knowledge. Therefore, the local community is regarded through the distinction; the fishermen and the local residents. Here, the local businesses are not considered since they mostly have the same relations as local residents and do not have any political rights in the area if they do not live there.

Fishermen

One of the most important collaborations on a local scale are the fishermen that work in this marine area. Since the fishermen have the ownership of parts of the sea, it is crucial to gain a strong collaboration with the fishermen associations in the area. The *Interview with Milton Magnere* (2024) explained the current collaboration with the fishermen in Maitencillo regarding the kelp forest project there. Here, it became evident that the fishermen regarded the project as interesting due to the potential of increasing the biodiversity through the kelp forest project. Legislation only allows that the fishermen associations are owners of the kelp forest and the farming project. Therefore, there is a high dependency on these associations when scaling-up the project.

In order to gain this collaboration in other regions, it is important to stress the benefits which can be realized through the kelp forest project. The *Interview with Ricardo Silva and Carlos Vega* (2024) in Maitencillo showed that the fishermen of fishermen association Sindicato believe that the micro-ecosystem will be recovered by the kelp forest project and would result in the biodiversity which was present in the area in the past. They believe that this is very beneficial for the fishermen since this leads to more sellable resources. Moreover, the *Interview with Maria Martinez* (2024) showed the hesitant attitude of the local fishermen towards projects that benefit the entire community. Additionally, these fishermen are only interested in projects for which they get a financial reward. Therefore, as explained, it is crucial to highlight the potential financial benefits which the fishermen could receive by the project indirectly through the increase in biodiversity.

Another indirect way to achieve a collaboration with the local fishermen is through foundations which work closely with the fishermen in Chile. Examples could be the Capital Azul Foundation and Chile

Foundation which have set up a coastal communities network. Their approach has the goal to create sustainable management of coastal resources to which the fishermen will have to depend (Chile, 2023). Furthermore, these foundations could support the kelp forest project and make sure that awareness and pro-activeness regarding the project could be achieved on a larger scale among the fishermen.

Not only are the fishermen important in terms of legal collaborations, the fishermen are also important in terms of their resources and knowledge. The fishermen are very familiar with the marine areas, its surroundings and applications. Therefore, a collaboration with the fishermen could result in a better understanding of the different aspects of the area. The *Interview with Fishermen's Federation of Quintero* (2024) showed the possibility that the fishermen could explain where the previous kelp forests were located which now have been removed. This type of collaboration can be useful to gain better insights on where the kelp forest has the highest potential to be successful, based on past experiences.

Thus, it can be concluded that the fishermen associations are very important stakeholders in regards to the direct initiation of the kelp forest in new regions. Therefore, it is crucial to make fishermen aware of the potential benefits of creating a kelp forest project within the areas that have their ownership. Firstly, it can be explored to what extent larger scale communications systems such as foundations can be used to activate fishermen to collaborate with the kelp forest project. Moreover, a more personal approach can lead to more convincing locally, explaining the other benefits which the algae might have for the fishermen and the marine aquaculture. Also, the fishermen have important knowledge and resources which can give valuable insights for scaling-up the project successfully in new areas.

Local residents

In line with the fishermen, the collaboration with the local residents would mostly revolve around the knowledge and resources which can be provided. Local awareness through local residents has been assessed elaborately and a lot of respondents expressed their concerns around the coastal erosion and the result to their living situation. Therefore, these insights can be used to create fitting solutions for new areas. As has been explained in chapter 6, co-creation can be used in order to gain knowledge from local residents on their concerns and beliefs regarding the project. Not only could this co-creation lead to better solutions on a larger scale, it also thus results in more awareness and support for the project in new, less aware communities.

The collaboration with local residents will mostly consist of information exchange. Here, the kelp forest project team could stimulate the education on coastal erosion and their project to local residents, supplying them with more knowledge. Not only would this lead to better environmentally educated residents, but also to a higher potential of new people interested in joining the research or related environmental projects. In exchange, the local residents share their knowledge about the area and the pitfalls for the project. Nevertheless, this new gained awareness and knowledge might assure that they perceive the coastal erosion problem of higher priority. Therefore, their new perception might as has been explained lead to different political preferences in terms of elections where they get to vote.

However, the social challenges showed that local residents could potentially be hesitant towards the increase of kelp in their sea. It is also important to make local residents aware of all the benefits in which the kelp forest project could result in. The *Interview with Milton Magnere* (2024) showed that the kelp forest does not only lead to results for the local problem of coastal erosion, but also for example for the dissolving of metal in the water. Magnere explains that the community of Quintero currently experiences this problem and that the kelp forest project would therefore also be beneficial. Therefore, like the fishermen, local residents need to be aware of all the benefits which could be the result of the kelp forest project. This can also be done through the proposed strategy in chapter 6 on creating awareness for local stakeholders.

9.3.2. Municipal and governmental bodies

The project requires collaboration with government and municipal bodies, not only for financial support but also for political and legal backing. This could help raise awareness and create additional collaborations.

Local government

Working with municipalities can offer opportunities to raise awareness in local communities. For example, strategies outlined in section 6.6 could be implemented more easily, such as visiting schools, organising community meetings, and reaching out to elderly homes. Moreover, additional local events

could be held, with better dissemination through local newspapers, creating community support and potential collaborations. Support from the municipality may also make it easier to establish local collaborations as described above. Furthermore, municipalities can assist with material supplies and provide workspace, as well as using their local networks to facilitate project efforts. Engaging with municipalities early in new areas for the implementation of kelp forests is essential, and presenting the project to multiple representatives within the municipality can help secure broader support, particularly in light of re-elections. Besides, municipalities can assist in navigating local regulations and provide political support to help with bureaucratic processes, such as obtaining permits or addressing environmental concerns. Lastly, it may be possible for local governments to advocate for the project at higher levels of the government, ensuring smoother transitions as the project scales up.

Regional government

Governmental bodies may be harder to contact, but they offer significant potential for financial support. The regional government of Valparaíso is a key institution to approach for funding and support. As mentioned before, the kelp project is currently in the running for the ”Fondo de Innovación para la Competitividad”, a grant of US$800,000 provided by the Valparaíso government, though it has not been secured yet. Unlike municipalities, the regional government has a broader scope, allowing them to address the coastal erosion issue on a larger scale and reach more people. This could include opportunities to raise awareness through local media channels widely viewed in the region. Additionally, the government's website prominently features information on regional investment programs and funding distribution (de Valparaíso, n.d.). To increase the chances of obtaining financial and political support, it is important for the project to arrange a formal meeting with multiple representatives from the Valparaíso government. In this manner, the government of Valparaíso may also assist in legal and regulatory processes, such as approval of the needed permits, Moreover, the regional government may have access to valuable data, research, and local expertise that could support the expansion of the kelp project. This way collaborations might be formed with research and knowledge institutions as described in 8.3.4. Finally, the project could try to integrate its own goals with broader regional development initiatives. By showing how the kelp forest contributes to long-term coastal resilience, tourism, and local livelihoods, the project may become a key part of regional planning strategies. However, this can only be done with a very high level of support from the regional government.

Central government

Lastly, the central government can play a key role in providing financial support and raising national awareness. With access to numerous national funding programs, engaging directly with relevant ministries and agencies can help secure financial resources for scaling up the project. However, competition for these funds is present, and establishing personal connections within these bodies can be challenging. Coastal erosion has not yet been a central focus for the government, but that needs to change. Aligning the kelp forest project with national priorities, such as climate adaptation, biodiversity protection, and marine conservation, it might be seen more as a priority. This could also make it easier to receive regulatory approvals. Additionally, the central government has access to public research institutions that could offer valuable expertise to scale up the project. Furthermore, together with the central government, national awareness campaigns might be created to highlight the importance of the kelp project in tackling environmental issues. Lastly, with central government involvement, the project could fight for regulatory reforms to make the permitting process for large-scale kelp farming more efficient, reducing approval timelines and delays.

9.3.3. Private sector

Private companies have the resources to grant funding to development projects and can therefore be considered as an interesting partner for collaborations. Since, for scaling up the project, funding is required to be able to start creating kelp forests in other areas. Not only are the private companies able to grant funding, also technical knowledge exchange can be very convenient for the upscale of the project. Nevertheless, the kelp forest project can also be beneficial for the operations of the local private companies, closely related to the shore. Therefore, this mutual collaboration between private companies and the kelp forest project is explored in terms of benefits for the operations of companies located to the shore and the funding and knowledge possibilities that the kelp forest project could acquire.

As noted by Magnere (2024), the kelp forest project offers potential benefits for companies operating along the shore, particularly in mitigating disruptions caused by high waves. For instance, Puerto Ventanas in Quintero Bay was forced to halt operations for 32 days due to intense wave activity. By addressing these challenges, the project can show its capacity to make a valuable contribution in return for the above-mentioned funding. The annual report of Puerto Ventanas in 2023, shows their active participation in an environmental program aimed to improve air quality in the Quintero region (S.A., 2023). This demonstrates their commitment to investing in environmentally focused solutions, making a potential collaboration with the kelp project an attractive opportunity.

To scale up the project, it will be essential to engage with various companies facing similar challenges along the Chilean coast. These companies, which often experience operational disruptions due to high waves and coastal erosion, could see the value in supporting the kelp forest initiative as a means to safeguard their operations.

Many private companies experience the urgency of the changing environment and how this affects the earth. Therefore, companies set up environmental impact programs to contribute to the enhancement of sustainability. Voluntary sustainability projects have increased within private companies, in order to make an effort in managing the environmental impacts of the industry (Lambin & Thorlakson, 2018). Lambin and Thorlakson (2018) state that companies use these environmental standards to enhance the environmental practices that their supply chains have and to share these practices with their customers. The *Interview with GNL Quintero* (2024) also showed that GNL takes environmental actions in the local community of their company which are set up in their sustainability guidelines. Therefore, companies like GNL have the possibility to collaborate with the kelp forest project for likewise goals. This could potentially result in the contribution of creating a environmentally resilient community, which is beneficial for the reputation of the company as well.

This concept of green investments in sustainability projects has a long history with private companies. One collaboration which is similar is the investment of Cargill, an argo company which has invested in seaweed farming with an emphasis on environmental benefits. Here the project The Red Seaweed Promise was sponsored by Cargill and they provided funding as well as knowledge which the project in for example the Philippines (Jan, n.d.). Thus, it can be concluded that the potential for finding a private company who is willing to make a green investment in the project is there. For the upscale of the project it is important to search for these collaborations with private companies. A first starting point in the upscale could be to explore the local companies in Quintero who experience a lot of issues with the pollution of the air. These companies might be willing to take on this type of collaboration, in order to provide more sustainable practices to the local communities. Since the raise of awareness is promoted throughout this project, the awareness could be raised for private companies with the same strategies as described in chapter 6.

9.3.4. Research institutions

The kelp project team in Maitencillo is already a collaboration of two different universities, the Universidad de Valparaíso and Pontificia Universidad Católica de Valparaíso. In order to gain more knowledge about kelp forests, a worldwide co-operation between research institutions could be established. The idea of restoring kelp forests to protect the coast is relatively new, but there are already some projects around the world, for instance in San Diego (USA), Sydney (Australia) and Cascais (Portugal).

The University of California San Diego scientist is working with a project called SeaTrees by Sustainable Surf to conduct scientific research into the best methods for restoring kelp forests in La Jolla and San Diego County. Sustainable Surf is a non-profit organisation based in California. The SeaTrees program protects and restores blue carbon coastal ecosystems globally, including kelp and mangrove forests, seaweed meadows, coral reefs, and coastal watersheds. These are the most powerful ecosystems on the planet for carbon sequestration and are biodiversity hotspots. They currently operate over 23 projects around the world, including 5 kelp forests in Portugal, Australia and 3 in the USA. As their goal is to develop 100 projects by 2030, the kelp forest project in Maitencillo could try to collaborate and gain a lot of extra knowledge and equipment (Surf, n.d.).

In Portugal the SeaTrees project also works together with SeaForester, an environmental impact company dedicated to restoring the forgotten forests in our ocean. They have different seaforestation and research and innovation projects about kelp forest in Portugal and Norway. They use a slightly different technique to replant the ocean and restore seaweed ecosystems. Their main approach is to seed

small stones with seaweed spores, grow them on land in specialist nurseries and then place them in the sea. The seeded rocks can be distributed from a boat without the need for divers or technical equipment, providing a low-cost and scalable solution to seaforestation. Furthermore, SeaForesters support local communities by bringing stakeholders together to plan and implement seaforestation projects to realise the huge potential of kelp forests in supporting marine health and livelihoods. They also raise awareness and generate public support for kelp forest restoration projects by introducing the public to the world of kelp and helping them to appreciate these impressive underwater forests. By working with this organisation, the Kelp Forest could gain more information on innovative seaforestation techniques and awareness raising. As this project started in 2009, they already have many different sponsors including companies, environmental organisations, government support and research partners such as the University of Western Australia and Bremen (SeaForester, n.d.). A very important next step for the Maitencillo Kelp Forest is to find a sponsor to expand the project.

Finally, the Kelp Forest Alliance, which brings together people and organisations working on kelp forest ecosystems and aims to improve the protection and restoration of these valuable ecosystems. They work to produce and facilitate global knowledge exchange on kelp forest management across languages and professional sectors. They also raise the profile of kelp forests and work towards greater conservation of these ecosystems.

The web platform serves as a hub for the Kelp Forest Alliance (KFA), promoting the importance of kelp ecosystems and hosting a project database, restoration guide and membership network. It provides a data portal for tracking restoration projects worldwide and a forum for collaboration. In collaboration with the Nature Conservancy, the platform also features a Kelp Restoration Guidebook, compiled from the insights of 50 experts from 45 institutions, which provides guidance on kelp restoration and shares success stories for future efforts. Its global mission is to protect and restore 4 million hectares of kelp forests by 2040.

Already 240 different kelp projects have been registered and 18849 ha have been restored. 10 of the 240 projects are located in Chile, the organisations of these kelp projects are; Universidad de Chile, Universidad Austral de Chile, Pontificia Universidad Católica de Chile, Universidad de Atacama, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, University Católica del Norte. The Maitencillo kelp project is not yet in the database. They could easily register to share their knowledge with the other projects and gain knowledge, especially from the other projects in Chile. They could also use their guide for further up-scaling (Alliance, n.d.). In conclusion, there are various international research institutions and many different types of kelp projects around the world to gain and share knowledge that could be useful in making the kelp forest more efficient or discovering the best way to scale up.

9.4. Roadmap to scale-up

In this final chapter, the recommendations to scale up the project are discussed through a roadmap to success. The roadmap consists of six phases: preparation, initiation, awareness, implementation, and evaluation.

9.4.1. Phase I: Preparation

To prepare the project for further expansion, it is important to work on the branding of the project. For example, at the moment there is not a clear name for the team and the project, neither is it possible to find the project anywhere online. We would advise to think of a catchy name, like the project in Portugal and Norway, SeaForester (Chapter 8.3). A potential name for the team could be ”KelpForce”, with a mission that resonates with the local community, such as restoring the lost kelp forests. The team could also adopt a logo, such as that of Australia’s Operation Crayweed (Crayweed, n.d.). In addition, creating a website is essential to provide information about the project, to raise awareness, and to attract potential supporters. There are many examples of good websites, such as those of SeaForester, SeaTrees and Operation Crayweed (Chapter 8.3).

Figure 9.2: Logo Operation Crayweed

After the preparation phase is done, it is time to apply for an official large-scale farming permit by the Chilean Armed Forces, instead of the current experimental permit. This process should already begin during this phase, as approving this permit could take up to 10 years. Until then, they will have to work with other (local) experimental permits.

9.4.2. Phase II: Initiation

After the preparation phase, the initiation phase will make sure that the project scale-up will be kick-started. Firstly, the current measurements of the kelp forest project in Maitencillo will be considered in order to provide insights on the working of the kelp forest project. These measurements are considered in twofold; the model measurements and the physical performance of the kelp forest in Maitencillo. With these measurements, it is assessed how the kelp forest project currently performs on a smaller scale in terms of algae growth, current possible reduction of waves, and results for coastal erosion locally. Moreover, the model will show predictions on how the kelp forest would perform on a larger scale. Lastly, the model will predict the kelp effects on wave attenuation during storms.

Afterwards, the current stakeholder relations and collaborations for funding are assessed for the Maitencillo kelp forest project. This analysis will identify which stakeholder relationships need to be maintained or created to secure funding for the project's scale-up. The stakeholder analysis will also reveal the attitude of the involved parties.

From these analyses, an area analysis will be performed on which new beaches should be targeted for the scale-up. The focus for this analysis is on the characteristics of the beach, the attitude of local stakeholders towards the project and the possible resources and collaborations within the area. It should be noted that the first scale-up is targeted on creating more kelp-forest projects locally instead of scaling-up the project nationally due to the complicated regulatory framework of farming permits in Chile.

Before actually applying for funding, it is important to have a clear overview of the benefits of the project and the value of these benefits, including tourism, employment, increased biodiversity, improved habitat for marine life leading to improved fisheries, increased tourism, carbon sequestration, nitrogen and phosphorus removal, and potential coastal protection resulting from the technical model. As mentioned in chapter 8.3 many different collaborations are discussed. The collaborations that could possibly bring in money are first the governmental bodies, such as the municipalities, regional governments and the central government. Once the governmental bodies have been engaged, the private sector can be contacted, including the large industries and local businesses. Another way to receive more money is through the use of the newly created website. Similar to the Operation Crayweed website (Crayweed, n.d.), a large button can be featured on the newly created website, allowing users to donate in exchange for planting a kelp plant.

Another crucial step for the scale-up for the kelp forest project is to convince the local fishermen of the importance of the project. This step should be completed before requesting the experimental permits since they have the power to accept or deny the kelp forest in their area of ownership. The *Interview with Milton Magnere* (2024) showed that fishermen in Quintero are hesitant towards accepting the project when they do not receive money for it. For this step, a fishermen coastal erosion program can be started as has been introduced in Chapter 8.3.1 with a collaboration with a foundation who works closely nationally with the fishermen. The benefits of creating kelp forest projects in their areas can be stressed and could lead to an open attitude towards the project. Within this program, the fishermen in Maitencillo can play an important role as pioneers.

Finally, when the funding has been gathered for the kelp forest project, permits can be applied for. As has been mentioned, these permits are experimental permits for the kelp farming since these are

the only permits that can be applied for in a short term. Thus, after the fishermen are convinced in the selected areas, the experimental permits are applied for in these specific areas. Moreover, like mentioned, the longer-term permits can take up to 10 years and therefore are not considered in this specific scale-up step.

9.4.3. Phase III: Awareness creation

The importance of creating awareness for the project has been explored in Chapter 6, here it was highlighted that more awareness will lead to more support and collaboration. Therefore, the current local coastal erosion awareness in Maitencillo and Quintero has been assessed. Furthermore, section 6.6. provides different steps in creating a promotion strategy for creating awareness regarding coastal erosion and the kelp forest project. For scaling-up the project, the recommendation is to focus on short term and immediate awareness promotion for the middle aged group. Different strategies for this age group have been provided in section 6.6 such as media awareness and co-creation opportunities. Here, the focus primarily lies on creating awareness on the possible interventions for coastal erosion, particularly with the kelp forest project. Co-creation could be beneficial not only for creating local awareness but also for implementing different insights from local stakeholders within the project.

Also, in this step, long term awareness strategies are set up for the youth group. Here, the focus lies on integrating coastal erosion awareness in national education, where children become aware of the causes of coastal erosion and the possible interventions. The elderly are rather informed on the project than the main focus for creating awareness when scaling-up.

Finally, it is noted that local awareness will be created for the areas that have been selected through the area analysis. Therefore, awareness on the kelp forest project will mostly be focused on these areas for this scale-up. Nevertheless, the goal is to create national awareness of coastal erosion and its threats. In the longer term, national awareness of the kelp forest project will be targeted, possibly with the help of the central government.

9.4.4. Phase IV: Collaborations

Next is the collaboration phase, which is crucial for scaling up the project. These involve merely the non-financial collaborations. It's essential to maintain and expand existing partnerships in Maitencillo, while building new ones in the recently selected areas. First, it's important to reach out to multiple contacts within the municipalities of these areas to establish strong, long-lasting relationships, even through elections. Municipalities can facilitate connections between the project team, local residents, and fishermen. As outlined in section 8.3.1, fishermen can play a key role by helping with legal challenges and providing valuable knowledge and resources. Likewise, local residents can share their concerns and perspectives on the project, which can contribute to its success. To keep both stakeholders satisfied, they should be well-informed about the potential benefits of the project, as described in phase II and III.

After establishing these relations, the project should also seek to collaborate with research institutions and universities engaged in similar projects. As outlined in section 8.3.4, several institutions could provide valuable insights and lessons on how to scale up and engage local communities. They could also offer connections to international environmental organisations and potential other universities as research partners.

Lastly, the project can try to establish collaborations with the regional and central government to make the project better known regionally and nationally through news channels and newspapers. As described in section 8.3.2, these agencies may also have access to valuable data, knowledge and local expertise. In this way, mitigating coastal erosion and thus the project, may also become a higher priority in Chilean politics.

Throughout the process, the project must maintain a strong relationship with the Chilean Armed Forces, as they are responsible for issuing the large-scale permit, which could take several years to secure. Regular progress update meetings during the experimental phase could help to keep this relationship productive.

9.4.5. Phase V: Implementation

In the implementation phase, the focus shifts from planning to taking concrete actions to expand the kelp forest project in the (newly) selected areas. First, the project team needs to grow, bringing in experts in marine biology, project management, coastal engineering, and logistics, along with local hires

(residents and fishermen) who understand the specific challenges of the areas selected for scale-up. Moreover, larger equipment, such as bigger boats and specialized kelp planting tools, will be essential for operating in these new areas. Also expanding the kelp seedling production through nurseries will ensure a steady supply of healthy plants.

Once the logistical basis is in place, the actual planting of kelp forests will begin, involving divers, local fishermen, and new technology to monitor the health and growth of the kelp. After the kelp is planted, continuous monitoring will be essential to track the health of the forest and its impact on coastal erosion and wave attenuation. This requires regular underwater inspections by divers, drone surveys, and data collection from sensors. This data will show any necessary adaptations, such as adjusting the spacing of the kelp, replacing damaged plants, or modifying the planting techniques to improve resilience.

9.4.6. Phase VI: Evaluation

After the project has been scaled up, the final phase is dedicated to a comprehensive evaluation. This involves assessing both the environmental impacts of the kelp forest and the effectiveness of stakeholder engagement. As mentioned in phase V, monitoring systems will track kelp growth, wave height reduction, and erosion control using underwater sensors. This data will be used to model the kelp effect on the wave attenuation and to compare and verify it with the current situation and predictions of the large-scale forest, as explained in phase II. The renewed model will also enable verification of whether the estimated impact of storms aligns with the actual effect.

Further, stakeholder evaluation will be an essential part of the evaluation. Feedback can therefore be gathered from local residents, fishermen, government officials, and private sector partners through surveys and workshops to assess their satisfaction with the project and its long-term benefits. This will help ensure continued support and identify areas for improvement in future expansions.

Lastly, the evaluation should consider any outstanding needs, such as the ongoing monitoring, further public awareness campaigns, and addressing any possible remaining regulatory barriers. This is needed to ensure the continuous success of the project and to identify possible adjustments for long-term implementation.

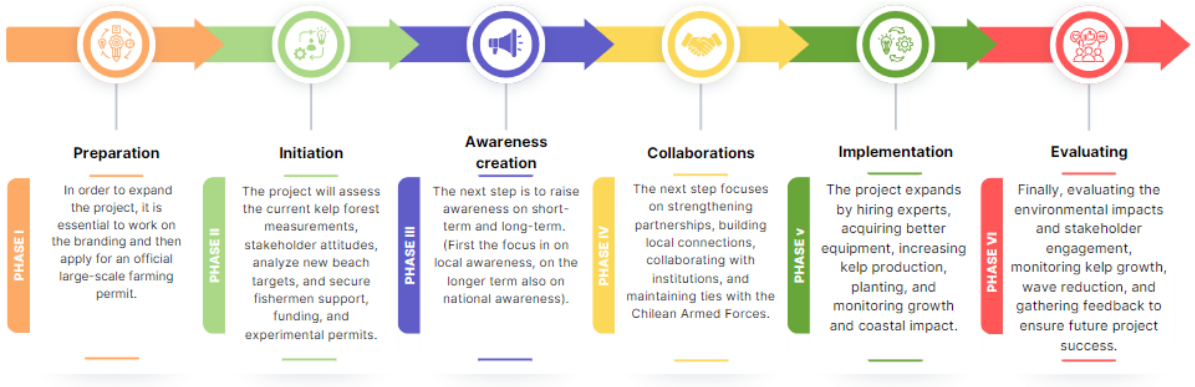


Figure 9.3: Roadmap to Scale-up

10 Conclusion

Research has shown that 80% of the Chilean beaches have eroded over the last four decades, likely due to increased storm-driven sand transport into the deep-water trench along the coast. To counteract this erosive trend, a proposal has been made to build kelp along the coast of Chile in order to attenuate waves and mitigate erosion. As of now, a prototype is being built in Maitencillo, but the concept has not been modeled as of yet, and social factors for broader implementation have not been examined.

Therefore the following research question is assessed:

"How can kelp be effectively applied as a nature-based solution to mitigate coastal erosion in Chile, considering both technical feasibility and socio-economic factors?"

It is concluded that preservation of coastal areas is crucial for local communities, also benefiting from social and economic benefits, such as tourism and recreation. Raising local awareness about the possible threats of coastal erosion is important for promoting effective interventions towards coastal erosion management. Research showed that well-informed local stakeholders result in proactive measures and that support is necessary to create a sustainable future for the Chilean coasts.

Furthermore, Chapter 6 showed that as a result of the survey assessment, it can be noted that the overall awareness of the respondents regarding the threats of coastal erosion in the assessed towns is considered high. However, the awareness regarding interventions which can be taken to combat coastal erosion was less present. While there is recognition of coastal erosion by experiencing the degradation of the beaches, there is a general lack of awareness of the urgency in addressing the issue. This presents both a challenge and an opportunity for projects like the kelp forest initiative, which could benefit from broader engagement and education efforts. This engagement is especially important when potentially wanting to operate on a larger scale.

From Chapter 7, the complicated network of relations becomes clear for the initiation of a kelp forest project. This gives a first glance of the needed collaborations for potentially scaling up the project. The municipality and fishermen's associations are important to manage closely, as they both have high power and interest due to political prioritisations and land ownership. It is important to engage with them early when scaling up the project, as interviews indicated they can be challenging to persuade. Moreover, the Chilean Armed Forces are a key stakeholder for scaling up, as they hold significant authority over large-scale farming permits and limited interest in individual kelp projects. Lastly, the power-interest-attitude grid reveals that most stakeholders have a neutral stance on the kelp forest project, indicating they only need to be kept satisfied. However, to keep stakeholders satisfied and to engage new parties, it is essential to provide evidence that the kelp forest project effectively mitigates coastal erosion.

Therefore, several models have been made in SWAN, as discussed in Chapter 8. These models showed that the current experimental set-up will only result in limited wave attenuation and wave energy dissipation. However, increasing the size and the density of the kelp forest in particular, will dramatically improve its performance. Increasing these does especially work well initially, but does eventually lead to a point where it barely improves the effectiveness of the forest. Therefore, blindly increasing them endlessly is not desirable.

The model also showed that the kelp performs exponentially better during storm events, as dissipation by vegetation scales with wave height cubed. This is very convenient, as these storms events are

mainly responsible for large-scale coastal erosion in Chile. Lining up the beach that has to be protected under the exact wave angle with the kelp forest will decrease the coastal erosion at the beach even more.

However, wave height reduction and dissipating wave energy are not the only positive effects of implementing the kelp forest. As described in Chapter 9, scaling-up the kelp forest will also have other environmental, social, cultural and economic opportunities. However, scaling up also presents challenges, such as environmental and economic risks and social and political challenges.

To address challenges and maximise opportunities for the project's success a roadmap is created, which will function as a stable factor independent of the technical results.

The project begins with a preparatory phase focused on branding and applying for an official large-scale farming permit, replacing the current experimental permit. The second phase is the initiation phase, the project will assess the current kelp forest measurements, stakeholder attitudes, analyse new beach targets, and secure fishermen support, funding, and renew the experimental permit, until the official permit is finalised. The next step is to raise awareness, to get more support for mitigating coastal erosion and scaling-up the kelp forest. Next is the collaboration phase, here they will focus on strengthening partnerships, collaborating with institutions, maintaining ties with the Chilean Armed Forces and building new connections. Once permits, funding, and partnerships are in place, the project will move to the implementation phase. Here, they'll hire experts, improve equipment reliability, and monitor the growth and impact of the new kelp forests. Finally, in the evaluation phase, the team will assess environmental outcomes, stakeholder engagement, and kelp growth effectiveness, gathering insights to shape the project's future and ensure long-term success.

A well-planned approach, strengthened partnerships, and technical adaptations are essential to successfully scale up the kelp forest project and protect Chile's coastline.

11 Discussion

11.1. Technical limitations

Causes of coastal erosion

The coastal erosion in Chile seems to have many different causes, with the most prominent one being an increase in the amount of storm events. As it is still not exactly clear how much this and other causes contribute to the total erosion, it remains harder to take measures. If the contribution of SLR appears to be larger for example, totally different measures may need to be taken. Research on the causes of coastal erosion is remains necessary.

Modelling

To model the effect of constructing a kelp forest in front of Maitencillo beach, SWAN software was chosen. SWAN is designed to evaluate hydrodynamic processes and is sensitive for depth changes. The entire model does therefore depend on the bathymetry used as input and the chosen grid size. For this model, the available data of depth measurements were rough and therefore had to be smoothed out. The smoothed bathymetry does induce a lot of uncertainty, influencing the wave patterns significantly.

The structure of the grid also influences the accuracy of the results, as the amount of data points are related to the mesh sizes. For this model, it was chosen to have a regular grid with mesh sizes of 5 [m] by 5 [m]. Using a smaller mesh size might have resulted in more accurate results. This would give more detailed information about the wave transformation and dissipation in the region of interest. However, it would have required a lot of computational time.

Another point of discussion is the implementation of the vegetation in the SWAN software. SWAN uses the equation of Mendez and Losada (2004), which is designed for rigid cylinders. This is not in compliance with the flexible vegetation of the kelp forest. As there are few to no studies about flexible vegetation and especially implementation in model software, this rigid cylinder method is still chosen to get a first idea of the effect of the kelp forest. When analysing the results, this needs to be kept in mind as there is no information about the range of fault yet. As soon as the data of the field experiment, which is being installed now, is available, the results of the model can be compared with the real life measurements.

The parameters that are used to describe the vegetation are drag force, vegetation height, diameter of the stems and density. The average of the these parameters had to be used for the whole kelp forest. This could have caused unrealistic results, as the depth varies and a constant kelp height of 10 meters is used. In reality, the kelp grows until the surface, when fully grown. The density of 4 [u/m^2] is based on a kelp mortality rate of 60 %. This mortality rate is highly sensitive to change, depending on local factors.

As no benchmarks runs have been executed, it is not possible to say that the modelling results are 100 % correct. The quantities of wave height change and energy flux change for example, cannot be considered as absolute truth. The relative effect of changing parameters however, can still be considered fairly trustworthy.

In some cases however, big changes in wave height and wave energy flux in front of the kelp forest followed from the models, while this should definitely not be the case. Before waves reach the kelp, they should be barely affected by it. These kind of results can not be considered realistic and can not be used to draw conclusions from.

11.2. Socio-economic limitations

Survey & interview limitations

Firstly, the different limitations of the survey assessment will be discussed. One of the limitations of the survey is the sample size of the respondents which have filled in the survey. Especially in Maitencillo it was experienced difficult to find many people who wanted to fill in the survey. This was mainly due to it being the off season, resulting in not many people on the streets who could be interviewed. Eventually, the initial minimum set number of respondents was reached. However, in order to make conclusions from the statistical analyses, more respondents would have led to more reliable conclusions. Therefore, the sample size is considered to be a limitation of the survey assessment. Additionally, since the sample size is not that big, the different influences were harder to analyse due to the different categories not being highly represented. For example, there were only 7 fishermen from Quintero who filled in the survey, this may lead to misleading conclusions from analyses. Overall, a larger sample size which has high representation of different characteristics would have led to more reliable analyses and conclusions.

Furthermore, the survey results led to some remarkable results which were not anticipated beforehand. For example, many of the respondents seemed to be aware of the kelp forest project in Maitencillo. Especially in Quintero, this was not in line with the initial expectations due to the project not being operated on a large scale yet. Another result which was not anticipated as well was that many respondents had overall awareness of the threats of coastal erosion. Before the survey researched was conducted, expectations were that many people would not fully be aware of the implications. However, there is the possibility that people feel the urge to fill in that they are aware of coastal erosion and the project, simply due to not wanting to seem unaware. This could be the result of how the survey was formulated, where the goal of the project is described and statements are bias. Nevertheless, this is a speculation and it could also be the case that the prior expectations on awareness were incorrect.

In addition, the companies we interviewed may not have been the most relevant to the kelp forest project. For example, the industrial company GNL was selected because it was the only company that responded and had time for a meeting within the limited timeframe of the project. We also had a meeting with Puerto Ventanas, but they cancelled just before the meeting, even though they would have benefited more from a kelp forest than GNL. Other companies, such as Aguas Pacifico, did not even respond to our requests.

Language barrier

For almost all of the interviews, except the one with GNL, we needed a translator. Usually Milton Magnere helped us with the translation. During the interviews, much was discussed in Spanish, but only the main points were translated into English for us. It's possible that this summary and translation was somewhat biased, as Milton is a member of the kelp forest research team and may have presented a more favourable view. It was impossible for us to fully understand everything that was said in Spanish. Milton Magnere also helped us when fishermen, residents and local businesses didn't understand some of the survey questions. His explanation may have had a bias in favour of a more positive perception of the project.

Limited information

A key point of discussion is the limitation of the information that was received. Much of the information in the report was provided by Milton Magnere, a member of the kelp research team, who had extensive knowledge of the processes involved in initiating the kelp forest in Maitencillo. However, verifying this information proved challenging due to language barriers. Consequently, it was difficult both to check the information through online sources and to confirm through other experts. Although Magnere spoke English well and facilitated interviews, site visits to the Maitencillo kelp project, and introductions to local fishermen, there may be some limitations to this assistance. The information provided, particularly around permits, funding, and the benefits of the kelp forest, may reflect a certain bias, as some of it seems to be influenced by Magnere's personal perspective. However, since the information was so hard to verify, this cannot be confirmed with certainty. To be sure, it would be necessary to find someone with the same knowledge of the project and fluency in English.

Cultural differences

The awareness strategies outlined in Chapter 6 are primarily based on European methods and literature, without consideration of potential cultural differences in Chile. To develop more effective strategies for

raising awareness in Chile, further research is needed on these differences. For instance, people in Chile tend to be more community-oriented than in individualistic Western countries, which may suggest that creating a sense of cooperation could be more effective (Parker & University, 2009). Therefore, awareness initiatives might need to be approached differently. However, further research into these cultural differences is needed before drawing any definitive conclusions.

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A

Interview with municipality of Puchuncaví

Interviewee: Anna Cabagal
Date: 02-10-2024
Translation by: Milton Magnere
Location: Puchuncaví

Who are you and what is your function?
My name is Anna Cabagal and I work in the environmental department of the municipality of Puchuncavi. Now I have been working for two years as an administrative employee at the environmental department (Medio Ambiente) and work on operations.

Do you think the Punchuncavi municipality considers coastal erosion a problem?
Yes, it is definitely a problem, we have seen spots in Puchuncaví where the beaches are diminishing. I live at Caleta Horcon, which is a beach nearby Puchuncavi. This beach specifically has already degraded, it is on the national list of degraded beaches because of coastal erosion. Moreover, it is on the main list of hazard spots as a result of coastal erosion in Chile.

Do you think the residents of Puchuncavi are aware of the importance of protecting the coastline?
Yes they are aware but they do not comprehend the whole phenomena, they need more education to actually understand what causes coastal erosion. So far, they know that their beaches are getting smaller, but they do not know the whole situation around it. Mainly, they would need more education to actually get a better understanding. They do regard this disappearance of the beaches as a problem. In my view, the problem is that the ice caps are melting and that the sea level is rising. This ocean and energy is collecting the sand of the beaches and making them smaller. I believe that the current kelp project is a great idea to protect the area because it is a natural way of protection.

Is the municipality currently trying to spread awareness in regards to coastal erosion? For example to educate these inhabitants and school children.
At this moment we are not working on awareness of the population specifically on this problem. Right now we have a project where we are working with 16 schools and 6 kindergartens here and we are teaching kids to take care of the environment. We do this by educating them on cleaning garbage and recycling, it is more on making the kids think environmentally. Thus, it is not specifically on the beaches topic but to make them act more environmentally aware.

Do you have any future plans to spread more awareness on coastal erosion to the local population?
So far, there are no plans for this specific issue. Right now the kelp forest team is the only actor who is spreading awareness specifically on the protection of coastal awareness. Currently, the only initiative to protect the coastal areas is by cleaning the beaches both in and out of the water.

Why did the municipality of Puchuncavi choose to support the project and collaborate?

It is very important to recover the area, so the sea and shoreline. We have seen the impact on the seashore and so far this is the very first idea we have heard going around. That is why the municipality of Puchuncaví wanted to support the project. Also we want to recover the fauna of the sea which can be restored by the kelp forest.

Do you also feel like it is important for the local economy to restore the beaches with the project?
Yes definitely, it is a fisher business over here and we see that the fishermen have the most advantage of this. This is due to the fact that they can do aqua culture because of this kelp forest. For example, they can sell products out of harvesting and manage the farming properly. When the fishermen do not get fish out of the sea, they could have this package that they could sell pieces of. It has been a culture here that people collect seaweed out of the sea and sell it to, for example, China. Right now they are working on a protection wall at the beach of Horcon, because the waves actually get to the streets. The fishermen have houses there and they are building new structural buildings here.

Do you think that the kelp forest application could have negative effects?
In Horcon there is a spot where there is very low current, therefore all the seaweed goes there and stays there. So the negative impact would be that the seaweed would come out of the ocean and into the beach, thus covering the beach. There used to be people who collected this seaweed and dried it to sell it. Right now, people do not really do this anymore on a large scale, but if this were to happen again, it could turn into a business again. There is not unity as there used to be before on this, some people still do this themselves. Potentially, this could turn into a business where seaweed is collected on a larger scale again so I do not regard it as a very negative effect.

How do you think that the kelp forest project could potentially be scaled-up? Do you have any recommendations from the municipality?
Here I think we should start with the schools, educating the kids on coastal erosion and its results. Also, funds should be collected from private companies, industrial companies for example. Then the project could be replicated in all AMERB areas that we have around here.

Does the municipality collaborate with environmental agencies or research institutions for coastal related issues?
We mainly collaborate with universities, so far the main collaboration is on environmental issues rather than coastal issues in specific. Sometimes, students are sent or NGO's come to sample the water of the wetlands. They are monitoring the quality of the water at these wetlands. There is a huge industrial complex beside and the main wind can make sure that the pollution of this area can come along. This was a very polluted area before and they are monitoring how this has changed. Also, there are monitoring stations to check the air quality at different places. Additionally there is an environmental services office of the government which is here, in Puchuncaví. When there is any event of pollution or conflict with the population, they go from here and collect information to go to the environmental ministry. From here they go into trials with polluting industries.

Are there currently any regulations for the removal of algae?
I am not sure to be honest, I know there are some regulations on the amount of algae that you can take from the AMERBS. However, from the open areas I do not really think that there are any strict regulations from that. If you go into the fishermen's beaches, you see that they just take all of the seaweed out of the water. You can go and collect some if you want to eat but these people take it for industrial purposes. There is very little control in this, the coastal areas are mostly in control of the marine army.

B

Interview with mayor of Puchuncaví

Interviewee: Marcos Morales Ureta
Date: 02-10-2024
Translation by: Milton Magnere
Location: Puchuncaví

Do you have any plans for mitigating coastal erosion?
There is no program of coastal erosion, they have an agreement with one university. The made a spot where you can take the same picture all the time (to see the differences). They are building a wall to protect on the shore, the money was there but there was nothing going on. There is not even a program from the central government to face the erosion. There is one project where the Horcon beach is part of. There are 17 different caletas with a huge investment from the central government, where there are building structures to protect the shore. They are building that right now. The government thinks it's a problem but they do not have a policy. You don't make walls in the water because you don't know how it will behave and it will be a large investment a you don't see it. He created an international association of beaches that do sport, they have 6 countries (Hawaii, Colombia, Uruguay, Ecuador, mexico and chili) that are involved. The only municipality that is subscribed to this association is Puchuncavi. There is an information network where everything that anyone of the association has to show, they will share it all together. Name of the association: Association latin american of sport and tourism.

Do you think local residents should be more informed about coastal erosion and how to protect the coast?
They don't have awareness of coastal erosion. They are focussing on cleaning the beach right now. They are teaching in schools how to be cleaner and produce less garbage. There is still only reactive with the 2 beach cleaning events. They want to be proactive, therefore they need to teach kids in schools. The basis of the problem is to be proactive, even before the garbage dropping instead of collecting it afterwards. They haven't faced the coastal erosion problem yet, so they focus more on the education of cleaning. We see that the fishermen, divers and surfers know that there is the problem with erosion because they live there. Other people do not really notice is because they only come there for a minute.

Do you think local companies next to the beaches, like restaurants, hotels and shops are aware of coastal erosion?
He thinks local companies are not aware like restaurants and businesses. They asked for money from the government to fix the problem, they just want a short term solution, but are not involved in coastal erosion. When he got into the government as a mayor, he found that there was an association of 12 different municipalidades to develop the tourism at the seashore. He added this town to it and he is now in charge / president of the association. Now there are 45 municipalities collaborating on promoting tourism. First they were competing for who was the best municipality on sport and tourism, they changed that to share the shore. When one municipality makes it look beter, the other municipality has to do the same. Together they make a bigger offer for the tourism, they quit the competition idea, new policy to share.

Are there any other initiatives to improve the environment?
They erased the plastic, to pack anything anymore. They are doing it sustainable, they quit selling plastic to be sustainable. The municipality is trying to get rid of the “sacrifice zone” image. Therefore, they are now focusing on the following 3 spearheads: sustainability, sports and tourism. Journalism here makes a lot, when he arrives at the municipal government. In one of the first interviews the journalists used a language trying to describe you as a garbage spot, like the mayor of the tsjernobyl / sacrifice zone. He changed that language, to prevent that language to make sure that industries will not think they can pollute whatever they want, because it already is the garbage spot. The way the companies behave has to do with your language. They developed the first security officers for tourism. They protect the beach from garbage for example by telling people to behave. Next year, his policy is to give more structural tools for these security officers at the beach, for example 4x4 quads. They are also supporting the work that the army does, they want a better collaboration with the army to protect the beaches. The slogan of Puchuncavi “Where the countryside met with the ocean.” The slogan is in the logo of the armed shield.

C

Interview with fishermen's association of Maitencillo

Interviewees: Ricardo Silva and Carlos Vega
Date: 02-10-2024
Translation by: Milton Magnere
Location: Maitencillo

What are your names and your function?
I am Ricardo Silva and I am the president of the Fishermen's association of Caleta, Maitencillo. And I am Carlos Vega, I work as the councillor of the regional government of Valparaíso. For this, he got elected by the people. Moreover, he is a commercial diver.

What does the association do? How big is it?
Ricardo mentions that here are 40 persons within the association. As an union, they represent and protect the rights of the artisanal fishermen of the Caleta beach of Maitencillo. They support the establishment of benthic resource management and exploitation areas.

Do you experience coastal erosion and do you think it is a problem?
Carlos mentions that it is a very big problem indeed. However, Ricardo says that here in Maitencillo there has been none coastal erosion. He says that the sea has been going down because the tectonic Nazca plate goes over the Pacific plate and lifts the ocean. Therefore the beach is not degrading, it's getting bigger. He says that as a kid there were no houses on the right side (on the ocean side) and when there was a high tide the sea went all the way to the other side of what is now the street. He believes that the development of the coastal construction made by the people (the houses, the restaurants, the schools) are responsible for the problems with the beach reduction. These have all been developed without an organisation, they just started to build.

"Milton mentions that Ricardo sees it very different than everyone else and both Milton and Carlos question his statements."

What are the consequences of coastal erosion on the fishery?
Carlos mentions that we're losing the beaches on the central area of Chile. Ricardo says again that the problems are the responsibility of the ones who built along the shoreline.

How are you involved in the kelp project of Milton?
Ricardo is one of the partners of the project. The Sindicato (the union) owns the seaweed farm, it's their project. The permit that we (Milton's project) got from the National Agency of Fishery and Aquaculture is on their name, on the Sindicato's name. The farming project is property of the Sindicato, also everything we put on the water is their property. We (Milton's project) are the ones who receive the finances for doing the research and finance their farming.

What kind of agreements have been made between you?
They made an assembly and the project was voted for the whole assembly and they agreed to be part of this project. Because they are willing to the aquaculture farming. The agreements are mutual beneficial, between all the parties. All the structural stuff we create for the project is for the Sindicato and the fishermen. In return, they give us material, seaweed structures, and the people who can dive here. The human resources that work for our project (the fishermen and the divers) are given to us by the Sindicato.

Which effects do you expect from the kelp project? (Both positive and negative)
Ricardo does believe in the project because he saw that the waves lost their energy when they went through the seaweed forest that was naturally here before (approximately 50 years ago). They both don't see any negative effects for now, because the natural way was that there used to be a forest. So, they like the way it was because at that time there were a lot of natural resources in the sea. You could see a lot of sea shells, crabs, and fish. They lived in the forest. They believe that the recovery of this micro eco-system will bring the same amount of life that they used to have. This is very helpful for the Sindicato because those are the resources that they sell in the shops.

Have you see a difference in the attitude of the fishermen towards the prevention of coastal erosion or other environmental issues over the last decades?
Ricardo believes that the attitude is now worse than before. He does not believe in the effects of global warming, or climate change at all for that matter.

D

Interview with municipality of Quintero

Interviewee: Maria Gene Martinez
Date: 08-10-2024
Translation by: Milton Magnere
Location: Quintero

Can you shortly introduce yourself?
Yes, my name is Maria Gene Martinez. And I am an environmental profession for education in Quintero, from the environmental department.

Do you think the people in Quintero see coastal erosion as a problem?
Maybe, I think most of the people are complaining or worrying about the air quality. Not so much about the coastal erosion. They are also not so much aware of the coastal erosion of papagayo beach.

Does the Quintero government see coastal erosion as a problem?
Not really. They know about the problem and it is something they need to resolve, but it is not in the activities / on their agenda yet. They don't have specific plans to do something about the coastal erosion. Sometimes they have projects with companies or universities, about Technology, robotics, education but not something that is in the business as usual. It is not really the main activity right now.

Does the government try to Preserve the nature in the coastal area?
I want to say yes, but I think the priority is in the forest here. The Inland forest has more priority than the coastal area.

What do you think is the best way to spread awareness?
This year we have more communications with the community. We are doing more workshops with the schools or for the neighbors. We have a lot of education to introduce new projects. People have a lot of concerns when they propose a new project, they worry there will be more contamination, and pollution, more industries and worse air quality.

Does the municipality collaborate with NGO's?
They collaborate with 2 or 3 NGO's. Mostly for the responsible keeping of the pets, air quality is the most approachable thing now, not for the coastal erosion. The residents find air quality important.

Are there any regulations for using the coastal area for projects?
No, there is none.

Do you think the municipality is interested in a project like the kelp forest?
It depends, this year we are voting for a new major, so there is a lot of uncertainty. But I don't think it's

a priority.

Do you foresee any challenges in a project like the kelp forest?
These questions are more for milton. Mainly fishermen are in charge of the area, they are not interested in a project that is a benefit for the community as a whole. They want to see money and then they talk, it is not easy to approach them. Probably need to have regulations, because changing their minds is not easy.

Do you think the erosion has any affect on the local economy?
The local fishmongers are provided with fish not from the bay here but from outside. So the resources are not so much affected by erosion. Before covid, the industry was more affected by the pollution, after covid the bay was reborn a little bit. Now I don't hear so much about this problem.

How do you think the polluting companies influence the living environment in Quintero?
The industry companies do accomplish the norms, so all the environmental issues are within the rules. It is perception, you see the polluting companies and the name "sacrifice zone" makes the bad publicity. The norms are not breached. They have bad air quality results from the pollution, but they can not make the connection with the industry. They know that there is pollution and how much, but they do not know who was the one who polluted it and when, because this industrial complex has been here for 70 years at least. They started with a metal melting process plant.

Are there regulations and norms on the maximum pollution for the industry?
They have regulations and norms, but every company has their own monitors and sensors. That data is compared by the environmental minister. Only a few times is the data over the norm. The pollution of the metal is in the water, a research proved that the metal concentration in the bay was way too much in the beach here.

"The research also proved that the algaes make the metal less polluted because they oxidate it. Milton wants to use the kelp forest to fight against, to recover it."

E

Interview with the kelp forest research team

Interviewee: Milton Magnere
Date: 08-10-2024
Location: Quintero

How does the collaboration work between the project and the fishermen? What kind of agreements are made?
We asked them if they wanted to have aquaculture (in a small scale) in their area, which would increase the biodiversity. The fishermen were like, yes we would like to, but we would like to have mussels and oysters. So Milton, said that they could do this too, but they first needed funding and needed to start with the kelp. The authorization to do this kind of experiment can only be through aquaculture. Because there is no experimental forest in legislation. Therefore, we needed to find a way to make it legal. The fishermen (or actually the fishermen's association, the Sindicato) own the forest / the farming. The ownership is for the Sindicato only. I went to this association and showed them the project idea and asked them if they wanted to be part of it. Luckily, they wanted this, so we started doing the paperwork. First to apply for the funding, and second to ask for the permits to do the farming. I asked for this permit to the marine army (Chilean Armed Forces). The fishermen are very well regulated by the marine, and they need to give them updates often. The fastest model we could get a permit for, is experimental farming. The permit for large-scale farming takes about 10 years, so that wasn't possible. The permit is under the name of the Sindicato. They are the owners and responsible to the army, but we do the work.

From which department of the central government did you get US$200.000?
Under the Ministry of Science is a fund which is called ANID (Agencia Nacional de Investigación y Desarrollo).

From which department of the Valparaíso government could you possibly get US$800.000?
That's from the regional government, the funding is called FIC (Fondo de Innovación para la Competitividad).

Are local residents and fishermen in the coastal area dependent on each other in any way?
In the families of the residents there are fishermen. They own the restaurants, they have the shops, they lived there their whole lifes. The town of Maitencillo started with Playa Caleta and thus with the fishermen. They started with the restaurants, the little shops and the houses. The families of the fishermen are often owners of restaurants. Also they sell a lot of their land at the moment, since this is very valuable. They started with big pieces of land in Maitencillo and suddenly this becae very valuable.

Which materials did you exactly receive from the Puchuncaví municipality?
When we built the artificial reeves, they gave us all the stones, sand, water, and cement. Also the additives for the cement that makes it more biologically natural were given to us. They also gave us the spot where we operate and the cultural house where we could show our project to the authorities

was given to us as well.

Is there any collaboration with the municipality of Quintero?
Not in paper. When we looked for the huge boat for our operations, Maria Gene Martinez (the other interviewee) gave me all of her contacts. Through her I could talk to the owners of the ships. She's very well connected and she does help me with stuff like this.

Do you think it's possible to also have your kelp forest project in Quintero in the future?
I see it more on an industrial scale. There is plenty more than the erosion. For example capturing the metal that is dissolving in the water, that is a very huge problem here. So what I want to, I want to do more with the farming. You can farm more seaweed than right now. That could be one of the main subjects with Quintero, but we still need to talk to some of the big industries over there. For example, last year, Puerto Ventanas couldn't work for 32 days because of the intensity of the waves. So that's a lot of money. Therefore, it could be a good idea for them, but it would then be a private collaboration.

Do you know if the Valparaíso government is already planning to do something about coastal erosion somewhere else?
We spoke to Valparaíso. They are very willing to give us support for the idea. Pato did a physical model for them a few years ago and the proposal was to build a huge wall under water. However they said; why would we spend so much money on an idea that nobody sees. And that is now the same problem with our kelp forest idea. The regional government want to show off, so they only want to financially support something that could be seen by the residents.

Do you think the kelp forest could benefit companies in the Quintero bay, such as GNL and Puerto Ventanas?
Of course, because they need to operate. The wave height could reduce because of the kelp forest which could increase their operations. The waves don't allow the ships to be part the Puerto Ventanas. If we could find a way to lower the wave height, their non-operating days would be less. For GNL, I am less sure, but that's why I will go with you to the meeting to find out.

Earlier we already went on a field trip with Milton to the Papagallo beach in Quintero, where he gave us a lot of information. This was on 06-09-2024 and will also be written down. It wasn't an official interview, but we asked him quite a lot of questions already, and the answers were also used in the report.

"During the field trip, it was visible that the beach was significantly decreased due to the waves. It was shown that the waves had already had a large impact on the surroundings, as they had eroded a big part of the steps and walls which were close to the coast line. As for the algae in the water, most of it had been harvested to sell to other countries such as China. The algae market was especially profitable in the season when China had low algae production. Furthermore, the algae would be used for different kinds of products such as consumption, cosmetics or other applications. Over the last few years, the former algae forest had almost completely disappeared and the sea is left without much algae. This change in biodiversity in the sea has led to the beach disappearing bit by bit, due to the waves getting stronger and further into the mainland. Thus, the need for a solution is growing since the beach and its surroundings are affected more and more as time passes by. However, to actually apply the algae solution, a rather difficult road is ahead in terms of legislation.

The body that is allowed to give permits is the marine army, not the local government. Here, it takes approximately 10 years to get a permit for aquaculture farming and it is dependent on the preferences of the army. In the area of Maitencillo, the fishermen currently have the permit for the area and to be able to apply the kelp solution, they would have to be convinced to implement it in the area.

As for now, the army does not assign permits to farming of any kind, therefore getting the permit for themselves is rather difficult. The 'easier' way would be to convince the fisherman that the kelp application is efficient and should therefore be applied in the area. However, the attitude of the fisherman is not positive at the moment since they do not see the added value of the application. Moreover, the fisherman ask for a lot of money to apply the algaes in their area. Due to the fact that the fisherman currently get a lot of subsidies from the government for being a so-called sacrifice area, they want a lot of money for the algae farming.

The fishermen in Quintero are generally a bit older and therefore do not really get the importance of applying the algaes to mitigate coastal erosion problems. As for Maintencillo, there already was algae farming in the area by the fisherman, which resulted in a better understanding of why the algae would be beneficial for the area. Furthermore, the major of the town was already familiar with algae farming techniques so the local support was much higher in this area than in Quintero.

However, even when we have implemented the kelp forest, there remain certain risks. Since we use the same type of algae, a danger could be that a certain creature would eat up everything, leaving us with nothing. That would be a very big problem and is a scary uncertainty.”

F

Interview with GNL Quintero

Interviewees: Felipe Manriquez, Luc Sabbe, Alejandro Amorin, and Jorge Cantwel
Date: 09-10-2024
Location: Quintero

Note: The responses to the questions were merged from the different persons into one answer of the GNL company.

Can you introduce yourselves and your function within the company?
My name is Felipe Manriquez and I work as the Assistant Manager of Sustainability and Corporate Affairs. I have been working with the fishermen coves for fourteen years, so I know the Papagallo fishermen very well and the challenges from working with them. My name is Luc Sabbe and my function is as an Engineering and Asset Management Manager, I am responsible for the engineering here in the company. In the past I have worked together with the Belgium company VLIZ who is doing a lot of research on related projects like the kelp forest project at the Belgian coast. Hello, my name is Alejandro Amorin and I work as the plant manager at GNL. Within my function, I am responsible for operations and maintenance. I am Jorge Cantwell and I am the superintendent of hygiene and security at GNL. Also, I was born and raised in Quintero, so I have quite some experience with the history of Quintero and the Papagallo beach.

What is the reason for the location of GNL being next to the coast?
We are here near the sea because we have an energy terminal where we receive energy ships. There we unload the LNG and put it into a tank and then we use sea water to heat the NLG with this -160 degrees, it is this low temperature because the LNG is in liquid state. So we use seawater to increase the temperature and change the state from liquid to natural gas. Then we send it to the city through a pipeline. Quintero bay is one of the most refugee bays in the central zone of Chile. This is one of the best bays for industrial companies, the companies need to unload and load different things in vessels. This is a bay which is closely located to the main city of Santiago.The seawater at the end, came back to the sea, to the bay with a low temperature, 3 or 4 degrees less than the water inland. They are not heating this water, we use the heat of the water which is 12-15 degrees, depending on the season. The water temperature here is quite stable, this is caused by the current which came from Antartica. Thus we are using the heat of the water to regasyfing the LNG from -160 degrees to 3 degrees and then we are sending back the cold water which is 3-5 degrees cold, which is not so cold. Then we send it back to the area so this is one of the reasons why we are located so close to the sea.

Are your operations influenced by coastal erosion and the changing environmental conditions? Do the operations for example stop due to high waves?
Every time we have to coordinate the operation, the discharge of LNG. We need the authorization from the port authority, so if the port is closed, we can not use it. So we have some limits of operations if there is a swell, extreme waves or a storm then the port is closed. This happens now more often than before, in winter time the port is probably closed half of the time, approximately 40-50 percent of the time the port is closed. In summer time, 10 to 20 percent of the time the port is closed, so on average the port is closed around 30 percent of the time. This is caused by the bad weather conditions, this

is also caused by the earthquakes which are less predictable than the waves. Another issue which is most likely also related to the change of climate is that if the sea water gets warmer, then other sea life becomes present as well. Since we need to filter the water, this might cause problems as well.

The flow is very slow and we have a very big mesh, there is not a lot of current and the tide over here is in general also very small. The temperature however is very stable and low, the water is therefore cold.

If we have some issues in the terminal then we would close, but we make sure that everything is in good condition. Generally, everything is working and then we can receive the ships. With earthquakes we have to stop and when there is a tsunami alert in this region. Everything is designed against earthquakes as well, we have designed it to be high enough to protect it from the tsunami's. They have calculated the conditions of earthquakes and designed in a way that the foundations would stand through it.

What effect do you think the kelp forest would have for your operations? Do you see any benefits or dangers?

As for that, we are to say it like this 'worried' about the sea water intake line. As we only have one pipe which has a diameter of 1.6 metres and a length of 800 metres, we have to take the water out of the sea by pumps. We have pumps and big basins to accept the water from the sea but this pipe is very important. Thus if we have a lot of sea life in the pipe which is growing as well, it can be blocked or unstable the process. Therefore, this is a reason why at this moment we are injecting small amounts of the hypochlorite to prevent the growth of sea life in the pipe. This is mainly bacterial life and small larves, for example barnacles and very small organisms. We do not know how this will play out in the future, we have a big filter to prevent sea life from getting into the pipe. Now we are working with a Dutch company to monitor the sea life and its growth into the pipe, so we can adjust in a proper way the injection of the hypochlorite. At this moment it is working very well but because of the climate change you do not know what the impact could be. The only big problem could be that big swells destroy the project and it could end up in the pipe lines. This could be the risk for us, if not, the operations are restricted with big waves and big swells, not with small projects.

If you have a farm which attracts a lot of sea life, if it is close to the inland then it could mean that they end up in the system. There is a filter but it can still have an impact, this kind of process should thus probably have a safe distance. Moreover there should be a safe distance also for security reasons as there could be dangers of getting stuck into the pumps for example. It is a very big intake place, it is a huge area actually 6 metres wide and 2 metres high . One of the characteristics of this place, in the outside of this pipe, you do not have these strong currents. You do not feel the current when you are, for example diving, because you are outside of this area. If you have the pipe and you have this big structure, transform this pipe into a bigger pipe and that will make it very slow.

A lot of industries have problems with the big animals, such as sea lions. We do not have a problem with these big animals and smaller animals as well because of the mesh. The larvae and barnacles are the problem for us regarding the sea water intake through the pipes.

Did you ever experience environmental conflicts with local stakeholders such as residents or fishermen?

As for GNL, we do not have that many of these conflicts because we have very strong relationships with all the stakeholders from the beginning. We have a social investment program with the community. When the terminal was designed, we incorporated the best practices, principles with bottom lines that you must include in the big impact. The sea water is the big impact for us, since we take a lot of it. We must incorporate the best practices, we have to do a study with the best practices in the sea water processes. The best available solution was the velocity cap, the best available technology at that moment. So no, we have not had many big conflicts with fishermen and stakeholders because of this compromise with the best available technology principle. Moreover, our company is not so old yet, we have been operating for 15 years now. Also, we are the cleanest in the neighbourhood, the big problem in Quintero bay is the air quality. One of the first companies in the area was the copper melting, at the very beginning they did not have any treatment. The way to get rid of it was to just put it out, this was until 10 years ago maybe even less. From 2018 they started operating treatment plans in their businesses.

How does GNL engage with local communities to create environmental awareness?

For now, there is not really mental awareness, we try to work with the most important problems with the

community. Environmental awareness is a big issue but you have a lot of big issues here in Quintero. For example, two years ago there was no potable water available and sewage. This is one of the most important things, we are trying to work on that kind of problems and climate awareness is not the most important for now. But, from the very beginning we started working with the fishermen's coves, trying to change and to prove different from the main activities. For example, in Pappagallo we work in the creation of a diving centre. We did create a diving centre, we did a very good job with many of the fishermen and the farmers. However, the fishermen started fighting and at the end the diving centre disappeared and nothing happened.

Also, we do work a lot with the different coves in the area. For example, in Horcon, we created an aquaculture space with mussels and we tried to create a productive area where we have been working with them on many different things. It is difficult because the fishermen are not thinking in the long term, they are thinking now or tomorrow. You have to explain the benefits of the project, but they do not have this perspective. Therefore, you have to repeat it many times so we communicate a lot with them and we try to be transparent. We want to let people know the way it is and thus be transparent about, for example, emissions, changes and processes. Also, we have a lot of visitors that visit the sites, they can then see everything for themselves. Sometimes, it seems very clear and simple for yourself but it can be very difficult for others. If you get too much into detail, then people get lost.

Do you also work together with schools or educational institutes?

We try to start conversations with the aquaculture speciality within the school in Quintero. So we try to do something but we do not have enough leverage. There is an option and we try to do something with the fishermen and them but it is not easy.

Questions from GNL to the kelp forest project (to Milton):

What is the next step in the project?

Milton Magnere: We are working on writing the continuity project now in Maitencillo and we will continue with them. At the last assembly with fishermen, they voted in favour of growing the aquaculture into new species, not just the seaweed and also to mussels and oysters plants there. My job right now is writing those projects and applying for the permits, the fishermen and aquaculture agency take about one year to approve the project. It has been very teachful, we are starting with these aquaculture projects in Region de Valparaíso, the university never did it before. So far we are collecting for more compromise with the municipality of Puchuncavi with the mayor, we will soon sign this agreement with the university. This is to continue as partners in the project, to make them a bigger part of the project because they have an office of the sea. We are putting the technical area for that office, so we will start developing the project. Also, we need to make the kelp forest bigger, this may be a solution to protect the whole bay. We need to go further and thus understand how this works in real life and how it works with the bigger waves. Then we can take proper measurements of the energy dissipation. For the next funding that we are applying for, we need to know more about the biology process behind it. Our hypothesis is only mechanical, which is covered by what the law says that we shall show to the authorities. We are willing to make it in the other coves, first in Puchuncavi, and then see whether we can start the project in other municipalities. The main reason we could not have it in Quintero is because the fishermen did not want that, all the municipalities wanted it.

Is there a limitation to only apply it in the AMERBS?

We needed to get the permit fast because we have a two year period project funding. So the easier way, we talked to the marina and they said we could not do something like that because it was illegal. Well we are creating a seaweed farm, which is in the law. The main idea is that this is a farm, finally we decided as a team that we shall do it in AMERBS.

They were asking people like Google whether they had problems with the erosion. The lines were under the ground and the ground was being eroded. They just got the finance for this project but the hypothesis which how they slow down the erosion projects or even grow the beaches bigger. The industrial application of the idea shall be a big forest for the channel for the ships come through. If you have any .. to make your carbon footprint, you might want to take steps here. If you want to profit with this, it is very difficult. The system in mixed seabed, sandy and rocky. They want to recover beaches, they thought it would be make a big wall underwater. There was a huge budget for this but it was not possible because people can not see it and then do not want to invest in it. Right now we are in a pilot

so there is a minimal scale that they can model so that it will have impact on the waves. After that we decided that they need to proof that it works a little, they are looking for industrial applications such as that they can not use the port now. Puerto ventanas have 4 docking places and there is a big problem that the port is closed because they use a lot of money by this.

G

Interview with fishermen's federation of Quintero

Interviewee: **exact names still needed!!**
Date: 09-10-2024
Translation by: Milton Magnere and Mauricio Reyes
Location: Quintero

Can you all introduce yourselves and tell us about how long you've been living in Quintero?
Yes, my name is Patricio Tagle and I've lived my whole life in Quintero, for 65 years. And I am Ricardo and I've lived for 60 years here in Quintero, also my whole life. I am Alleandro and I've lived for 45 years in Quintero. We are all part of the Federacion de Pescadores Bahia Narau, Quintero.

How do you perceive coastal erosion and what do you think it results in? Have you seen changes in your environment?
They've experienced and seen it always. Here there is open water and the waves get into the shoreline and generate that erosion. New rocks are appearing where there used to be a beach. In the bay side, there is a place where they used to dive. However, they saw that right now the sand around it is fully gone and that it lays much deeper than first. There used to be a natural kelp forest in the Papagallo beach, which was so dense that they had to open it to dive inside. This is gone now. Also, they believe that the ocean is a lot stronger than before, because they see the amount of energy the waves have now.

Milton said; if you have more rock here, maybe you have more life. Because of pollution the shellfish is very weak, so there are no shellfish in the rock. They think it is because of the pollution. In the Quintero bay there used to be three big powerplants, now only one. There is a bit more life already.

Do they think that the coastal erosion problem is taken seriously around here? So are people aware of it?
No. Only people that work near the ocean, so fishermen etc, know that coastal erosion is going on. But the common residents don't know. The people that work in the sea and live near the sea are more aware.

Which actions do they think should be taken so that the regular people also take the coastal erosion problem seriously?

"antwoord is niet vertaald, misschien nog aan Mauricio vragen; rond 11min"

Would you be interested in implementing the kelp forest project here in Quintero?
Well, personally they are very interested. However, their fishermen's federation voted against this idea. The majority decided not to go. But the three interviewees voted in favour. This is because the other fishermen wanted money for it. In the past, they were more willing to work with projects like this. How-

ever, most of these projects used to get a lot of funding, and the fishermen got nothing. The old projects used only half of the money they received and then took off. Consequently, the fishermen believe that this project is just for taking the money, they don't believe in it anymore. They have had very bad experiences.

Do the fishermen (association) work together with big companies in the Quintero bay? (Such as GNL and Puerto Ventanas)
They do a cleaning of the beaches in the water and on the dry beach too. These are community services that they do, so the tourists don't see the garbage. This is in collaboration with these companies, and they also get paid for it. The next cleaning is at the fourth of December. It's an agreement between the companies and the fishermen's association. However, only the fishermen that truly work, get paid.

Does the fishermen association own all of the shores in this neighbourhood?
Yes they own all from Playa Libra to Playa Papagallo. They are allowed to use the resources, not the fish. So the ones that are fixed to the bottoms; craps, scallops etc. Further from the shore, the government is the owners of the water.

H

SPSS analysis output

H.1. Principal Component Analysis

Rotated Component Matrix[a]

	Component	
	1	2
I am aware of coastal erosion occurring along the Chilean coasts.	,773	
I believe coastal erosion poses a danger to Chilean beaches.	,902	
I have noticed changes in the beaches over the last few years.	,915	
I believe these issues should be tackled.	,884	
I am familiar with the concept of kelp farming as a method to prevent coastal erosion.		,762
I am interested in learning more about kelp farming or participating in activities related to it.		,764
I feel that I could get involved in local initiatives if I wanted to.		,754
I am concerned about the long-term effects of coastal erosion on my community.	,684	
I am aware of the ongoing kelp forest project at the Caleta beach.		,854
I am aware that the underwater kelp forest has been completely removed in the last 80 years at Papagallo beach.		,594

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 3 iterations.

Figure H.1: PCA analysis

H.2. Awareness assessment

H.2.1. Overall levels of awareness

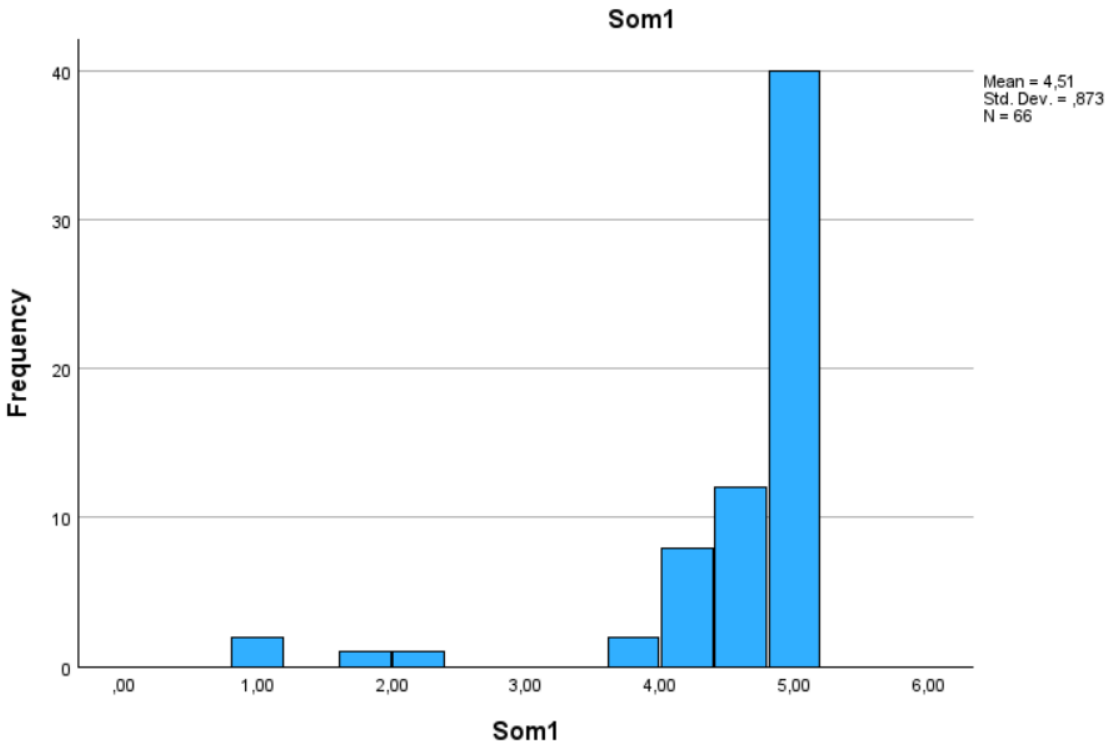

Figure H.2: Overall awareness of threats of coastal erosion

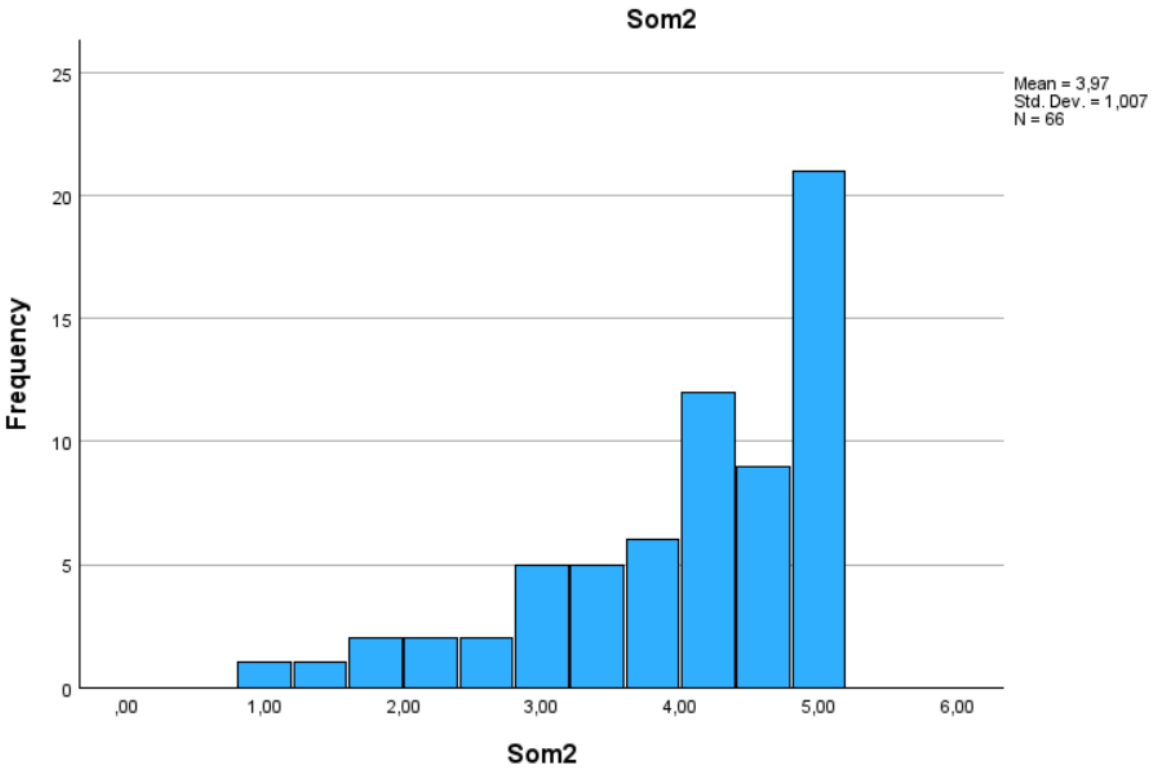

Figure H.3: Overall awareness of interventions on coastal erosion

H.2.2. Influence of age

Bayesian Estimates of Coefficients[a,b,c]

Parameter	Posterior Mode	Posterior Mean	Posterior Variance	95% Credible Interval Lower Bound	95% Credible Interval Upper Bound
age_group = 1,00	4,560	4,560	,081	4,000	5,120
age_group = 2,00	4,502	4,502	,020	4,226	4,779
age_group = 3,00	4,480	4,480	,054	4,023	4,937

a. Dependent Variable: Threats

b. Model: age_group

c. Assume standard reference priors.

Figure H.4: Influence of age on threats component

Bayesian Estimates of Coefficients[a,b,c]

Parameter	Posterior Mode	Posterior Mean	Posterior Variance	95% Credible Interval Lower Bound	95% Credible Interval Upper Bound
age_group = 1,00	3,580	3,580	,104	2,946	4,214
age_group = 2,00	3,976	3,976	,025	3,663	4,289
age_group = 3,00	4,227	4,227	,069	3,709	4,744

a. Dependent Variable: Interventions

b. Model: age_group

c. Assume standard reference priors.

Figure H.5: Influence of age on interventions component

H.2.3. Influences of town of residency

Bayesian Estimates of Coefficients[a,b,c]

Parameter	Posterior Mode	Posterior Mean	Posterior Variance	95% Credible Interval Lower Bound	95% Credible Interval Upper Bound
Town of residence = Maitencillo	4,536	4,536	,029	4,204	4,868
Town of residence = Quintero	4,484	4,484	,021	4,199	4,769

a. Dependent Variable: Threats

b. Model: Town of residence

c. Assume standard reference priors.

Figure H.6: Influence of town of residency on threats component

Bayesian Estimates of Coefficients[a,b,c]

Parameter	Posterior Mode	Posterior Mean	Posterior Variance	95% Credible Interval Lower Bound	95% Credible Interval Upper Bound
Town of residence = Maitencillo	3,864	3,864	,038	3,483	4,246
Town of residence = Quintero	4,053	4,053	,028	3,725	4,380

a. Dependent Variable: Interventions

b. Model: Town of residence

c. Assume standard reference priors.

Figure H.7: Influence of town of residency on threats component

H.2.4. Influence of stakeholder category

Bayesian Estimates of Coefficients[a,b,c]

Parameter	Posterior Mode	Posterior Mean	Posterior Variance	95% Credible Interval Lower Bound	95% Credible Interval Upper Bound
Category = Local residents	4,560	4,560	,026	4,243	4,877
Category = Fishermen	4,670	4,670	,039	4,282	5,058
Category = Local businesses	4,200	4,200	,049	3,767	4,633

a. Dependent Variable: Threats

b. Model: Category

c. Assume standard reference priors.

Figure H.8: Influence of stakeholder category on threats component

Bayesian Estimates of Coefficients[a,b,c]

Parameter	Posterior Mode	Posterior Mean	Posterior Variance	95% Credible Interval Lower Bound	95% Credible Interval Upper Bound
Category = Local residents	3,800	3,800	,034	3,440	4,160
Category = Fishermen	4,370	4,370	,050	3,929	4,811
Category = Local businesses	3,800	3,800	,063	3,307	4,293

a. Dependent Variable: Interventions

b. Model: Category

c. Assume standard reference priors.

Figure H.9: Influence of stakeholder category on interventions component

I

Survey

LOCAL RESIDENTS

SURVEY

Universidad de Valparaíso CHILE

TU Delft

PERSONAL INFORMATION:

NAME: _____ AGE: _____ PROFESSION: _____

GENDER: ○ Male ○ Female ○ Other

CITY OF RESIDENCE: _____

PROJECT DESCRIPTION

We are a group of Dutch students, performing a project on coastal erosion in Chile. These answers will help us with the research of algae use for protecting the Chilean beaches. Your answers will be published in our research paper, by filling in this survey, you give permission for this. Thank you for your participation!

Coastal erosion refers to the loss of land across the shoreline due to the action of waves, currents, or other impacts of storms. The **kelp** used in this research look like big underwater seaweed plants.

STATEMENTS:	RATING SCALE: Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I am aware of coastal erosion occurring along the Chilean coasts.	○	○	○	○	○
I believe coastal erosion poses a danger to Chilean beaches.	○	○	○	○	○
I have noticed changes in the beaches over the last few years, such as a reduction in beach length or a decrease in marine species diversity.	○	○	○	○	○
If yes, I believe these issues should be tackled.	○	○	○	○	○
I am familiar with the concept of kelp farming as a method to prevent coastal erosion.	○	○	○	○	○
I am interested in learning more about kelp farming or participating in activities related to it.	○	○	○	○	○
I feel that I could get involved in local initiatives if I wanted to.	○	○	○	○	○
I am concerned about the long-term effects of coastal erosion on my community.	○	○	○	○	○
Maitencillo: I am aware of the ongoing kelp forest project at the Caleta beach, led by the research team of the universities in Valparaíso.	○	○	○	○	○
Quintero: I am aware that the underwater kelp forest has been completely removed in the last 80 years.	○	○	○	○	○

Turn the page for the open questions

LOCAL RESIDENTS

OPEN QUESTIONS

How has coastal erosion impacted your personal experience with the beach or local environment? Do you think it will affect for example your property or community in the future?

Do you see any disadvantages of introducing kelp farming to your local beaches? Think of how more algae could change the beach surroundings and your personal experiences.

How do you think that kelp farming could influence your living situation?

Thank you for you participation!

J

Energy density spectra 2D model

This Appendix contains the Energy Density Spectra of all 6 locations for all 12 runs of the 2D model. The first row represents the line in between the kelp forest and Caleta beach and the second row represents the line that is in the same direction as the angle of incidence.

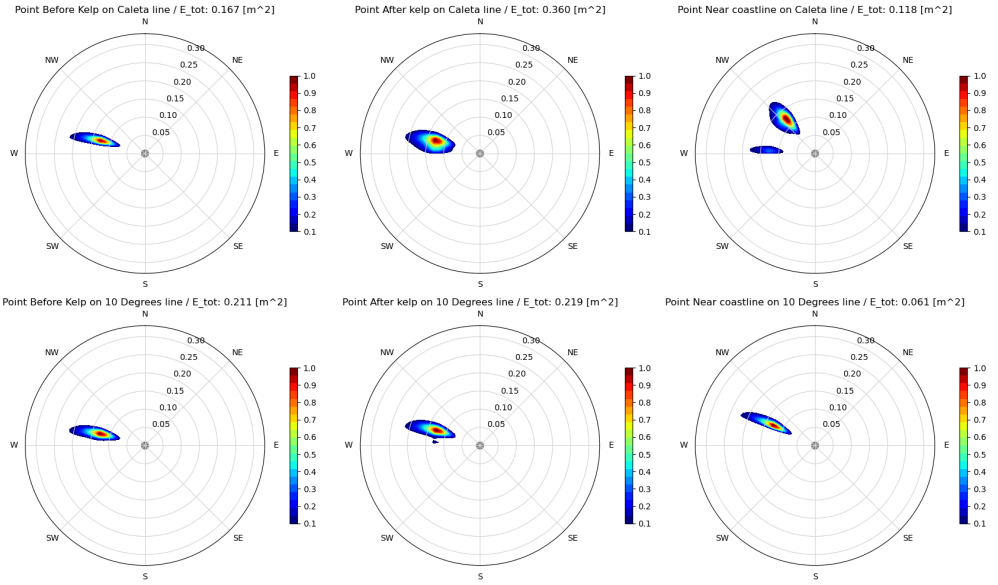

Figure J.1: Energy Density Spectrum of Run 1 over all directions

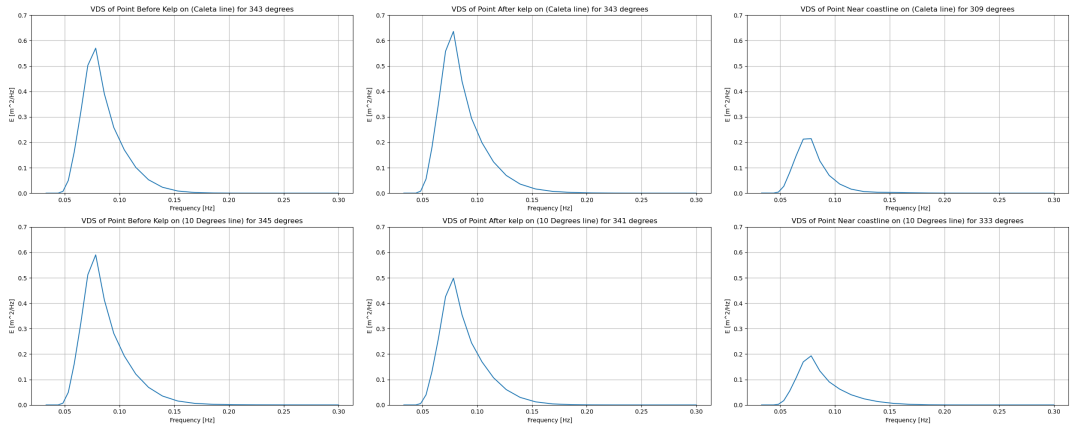

Figure J.2: Energy Density Spectrum of Run 1 in the most Energetic direction

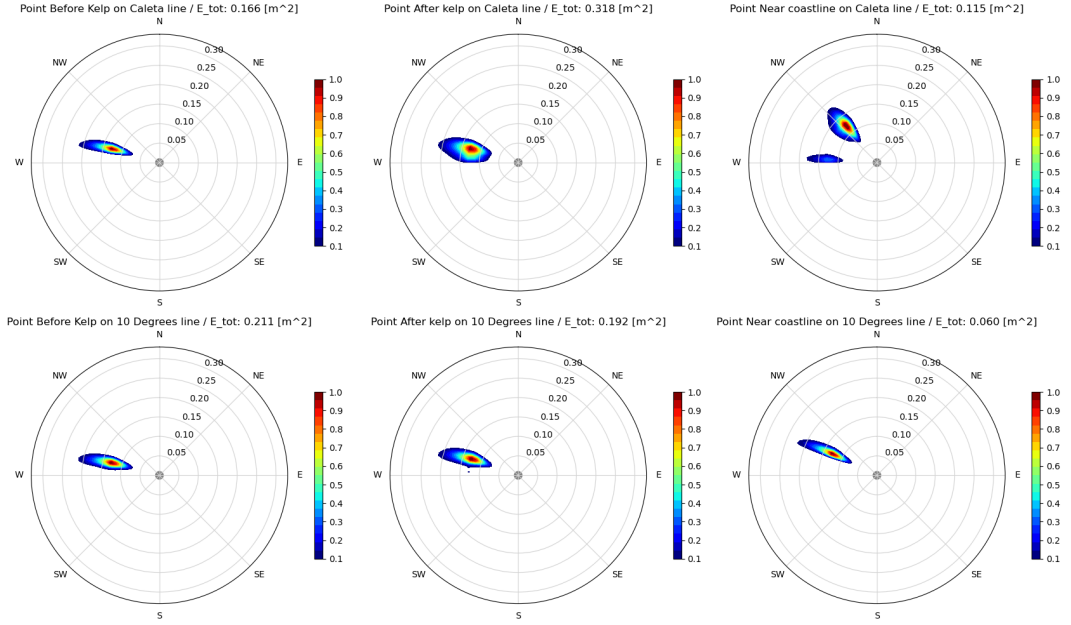

Figure J.3: Energy Density Spectrum of Run 2 over all directions

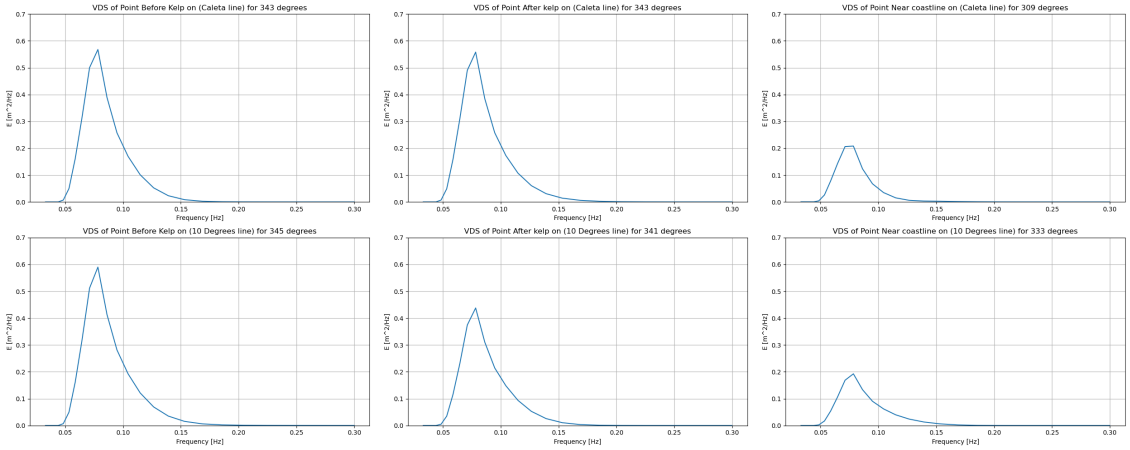

Figure J.4: Energy Density Spectrum of Run 2 in the most Energetic direction

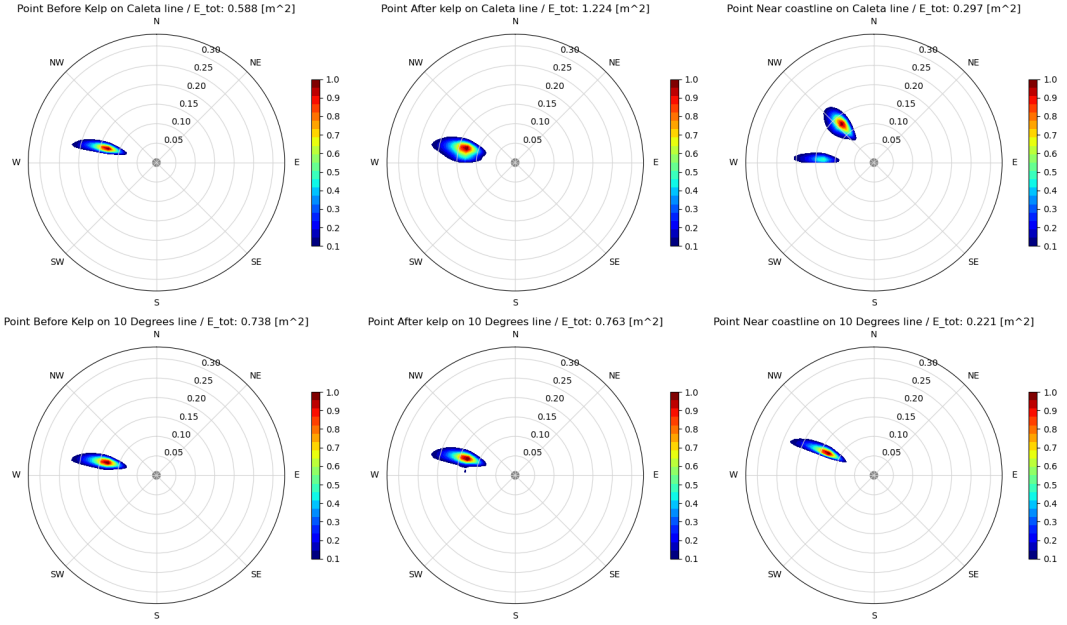

Figure J.5: Energy Density Spectrum of Run 3 over all directions

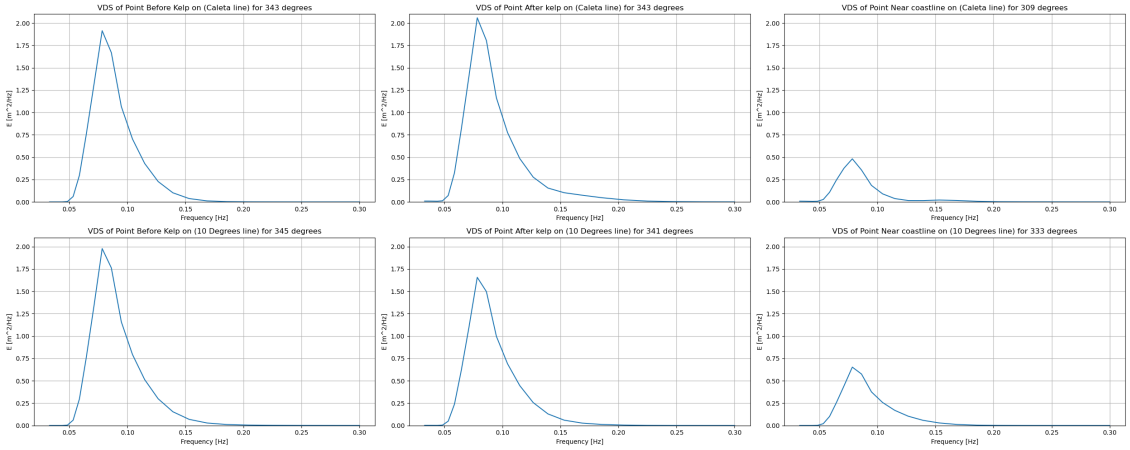

Figure J.6: Energy Density Spectrum of Run 3 in the most Energetic direction

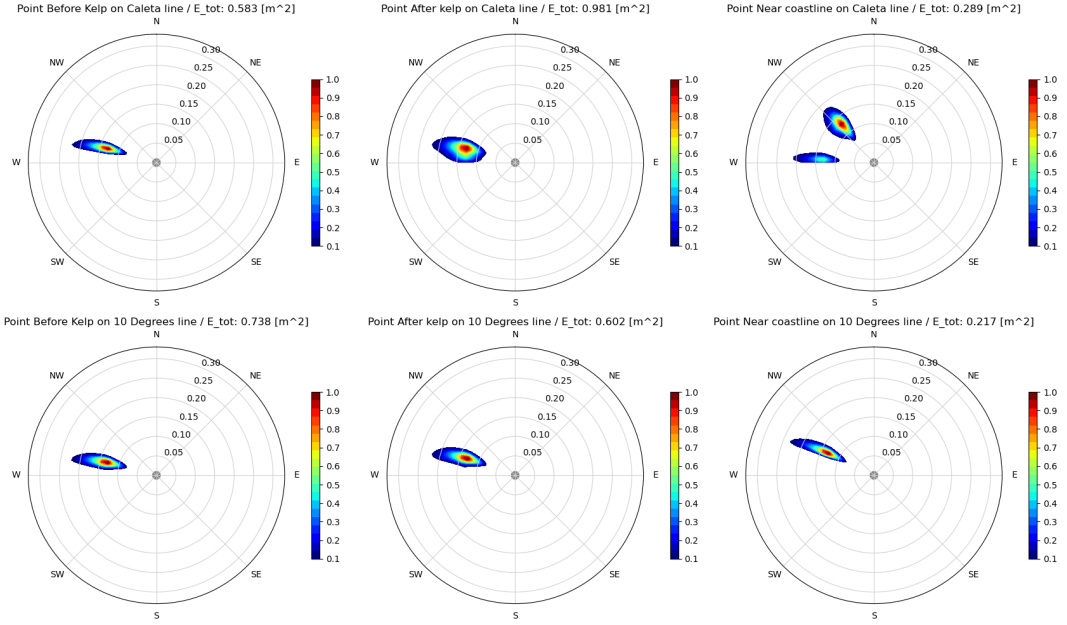

Figure J.7: Energy Density Spectrum of Run 4 over all directions

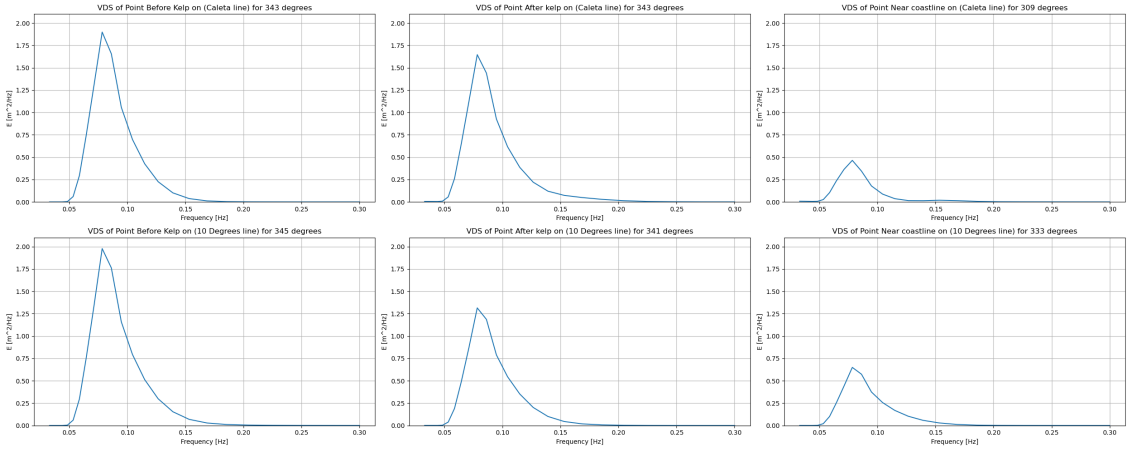

Figure J.8: Energy Density Spectrum of Run 4 in the most Energetic direction

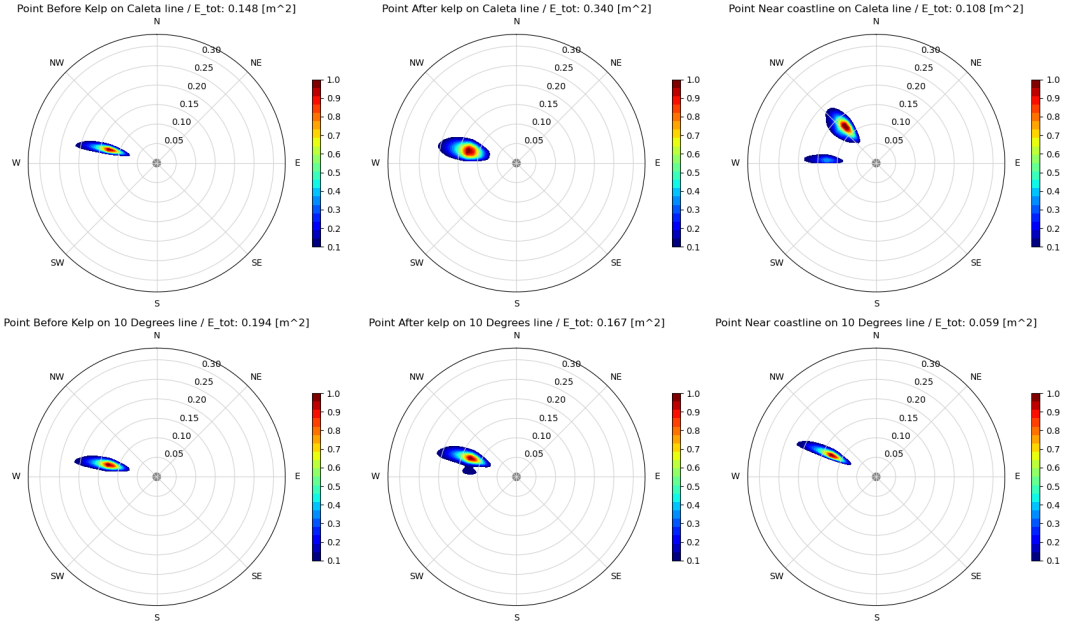

Figure J.9: Energy Density Spectrum of Run 5 over all directions

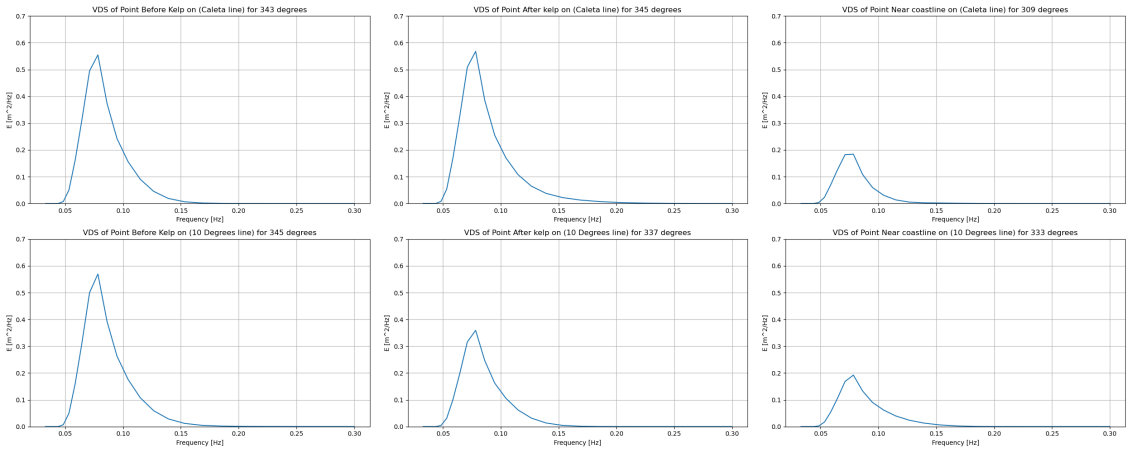

Figure J.10: Energy Density Spectrum of Run 5 in the most Energetic direction

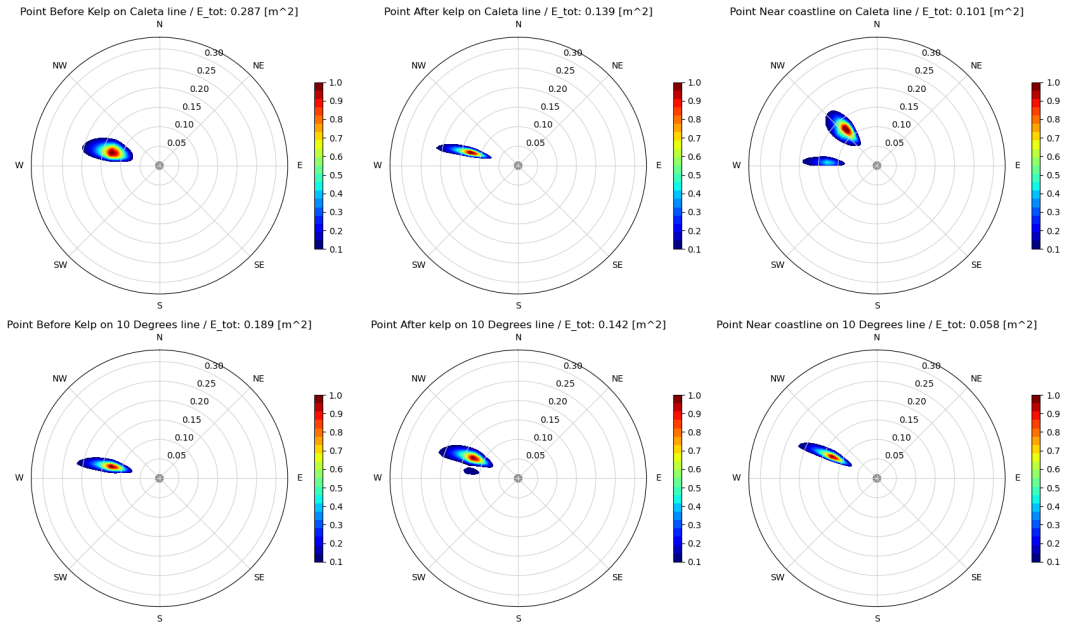

Figure J.11: Energy Density Spectrum of Run 6 over all directions

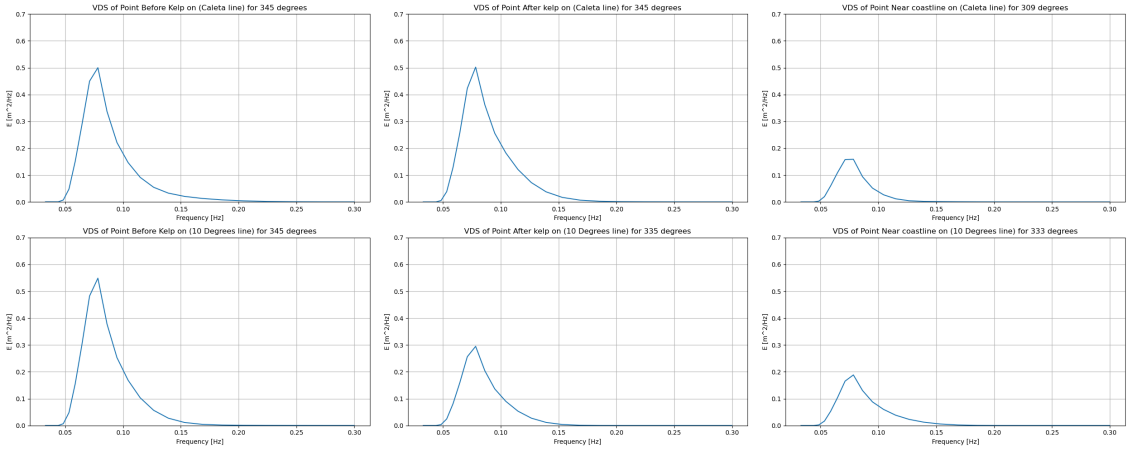

Figure J.12: Energy Density Spectrum of Run 6 in the most Energetic direction

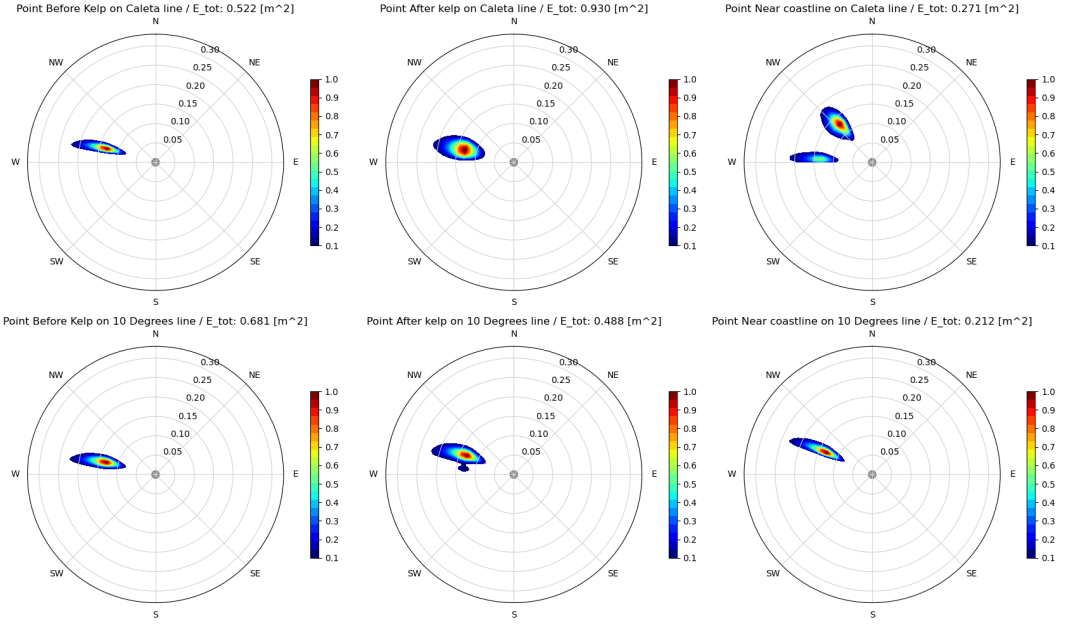

Figure J.13: Energy Density Spectrum of Run 7 over all directions

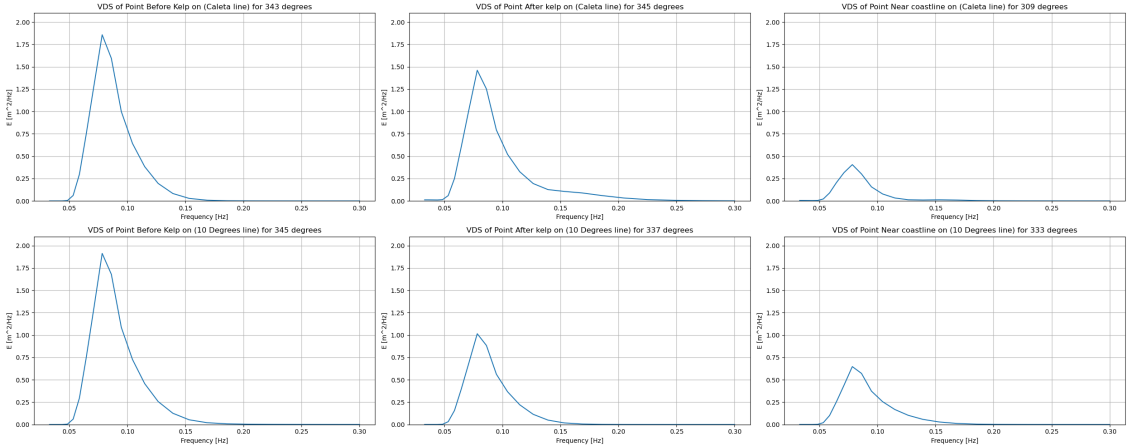

Figure J.14: Energy Density Spectrum of Run 7 in the most Energetic direction

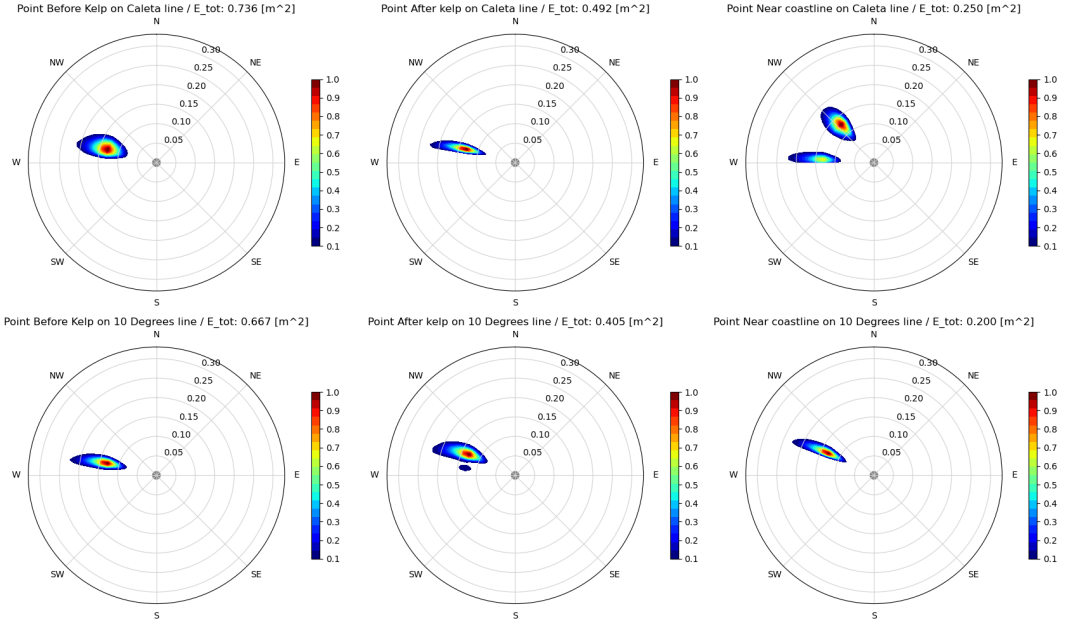

Figure J.15: Energy Density Spectrum of Run 8 over all directions

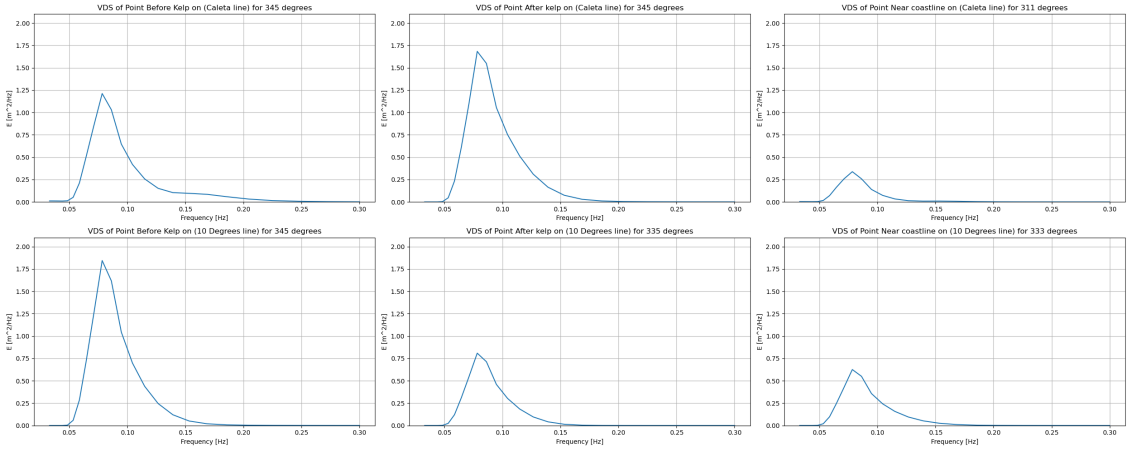

Figure J.16: Energy Density Spectrum of Run 8 in the most Energetic direction

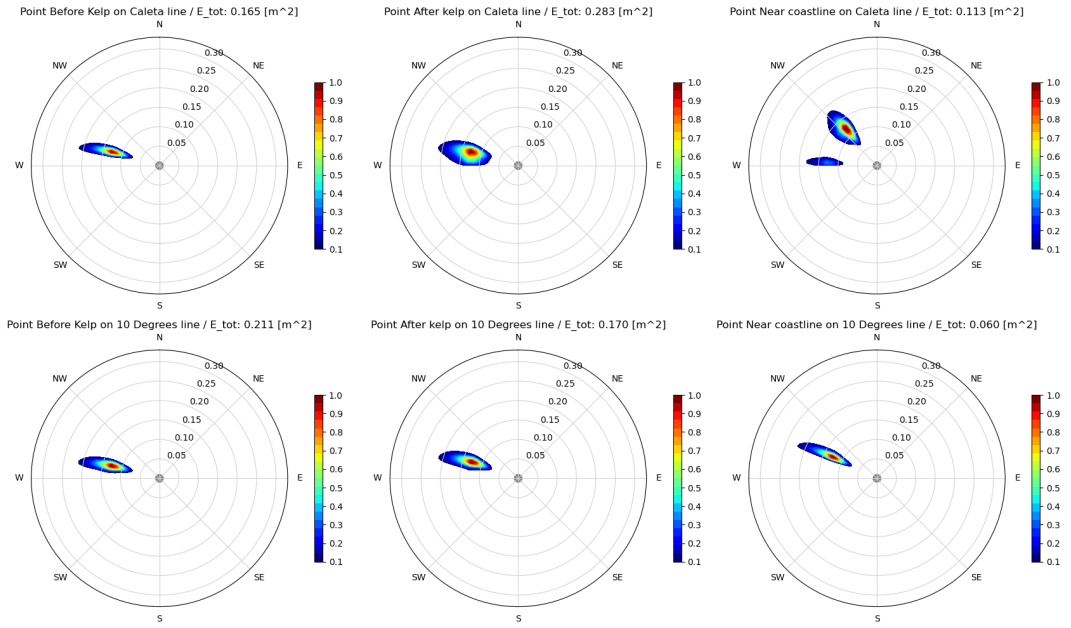

Figure J.17: Energy Density Spectrum of Run 9 over all directions

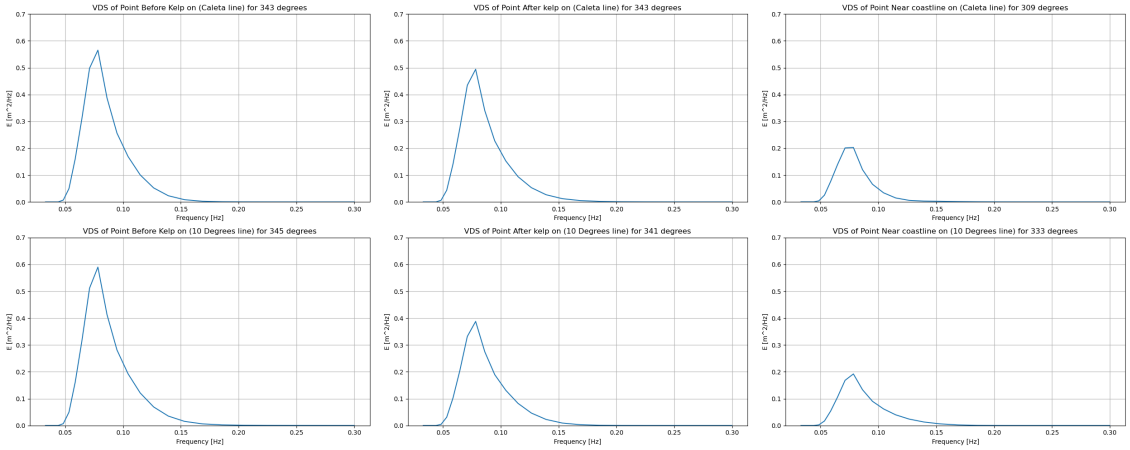

Figure J.18: Energy Density Spectrum of Run 9 in the most Energetic direction

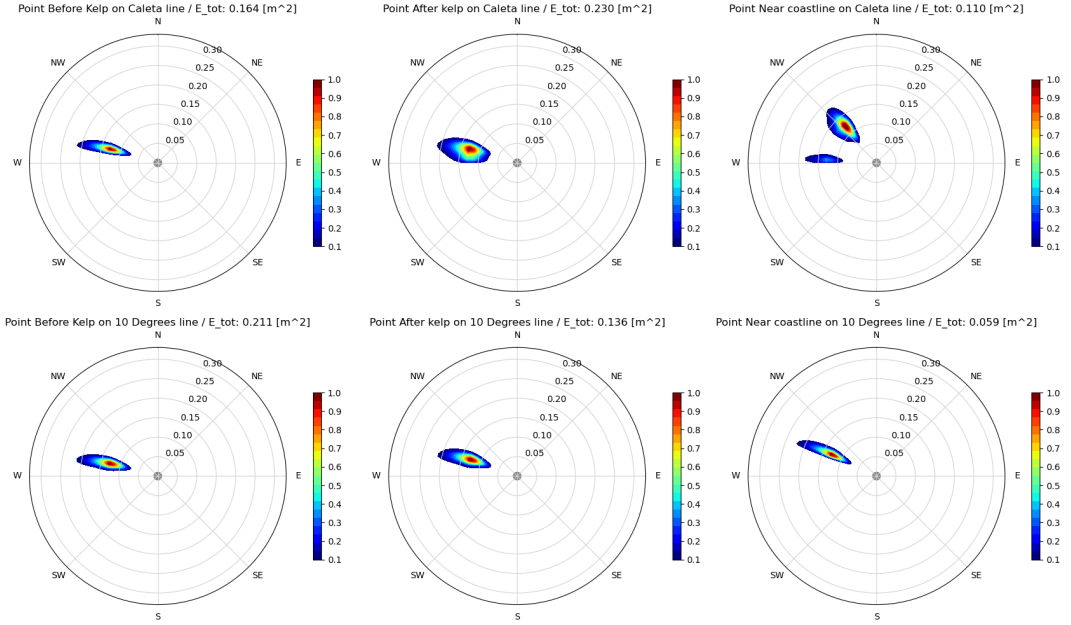

Figure J.19: Energy Density Spectrum of Run 10 over all directions

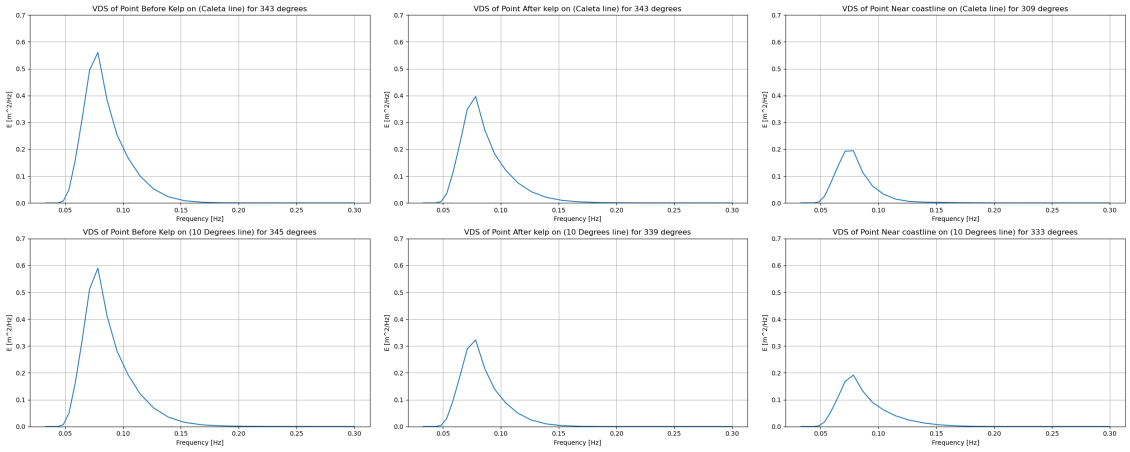

Figure J.20: Energy Density Spectrum of Run 10 in the most Energetic direction

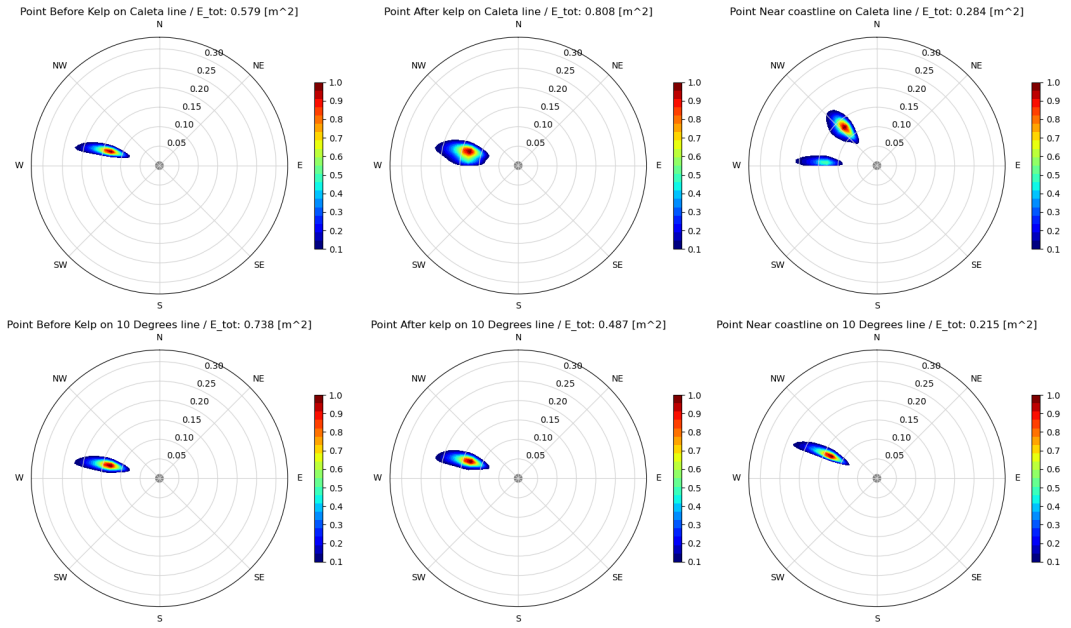

Figure J.21: Energy Density Spectrum of Run 11 over all directions

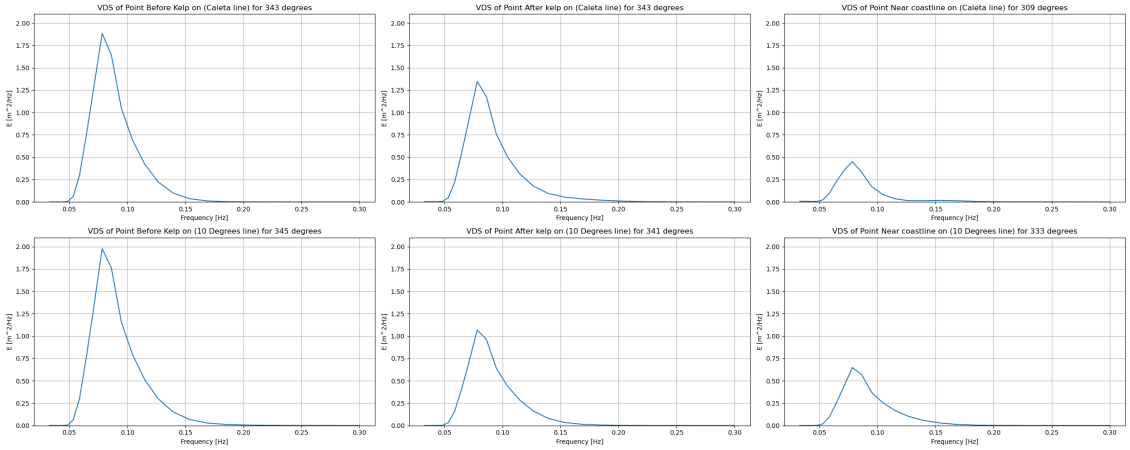

Figure J.22: Energy Density Spectrum of Run 11 in the most Energetic direction

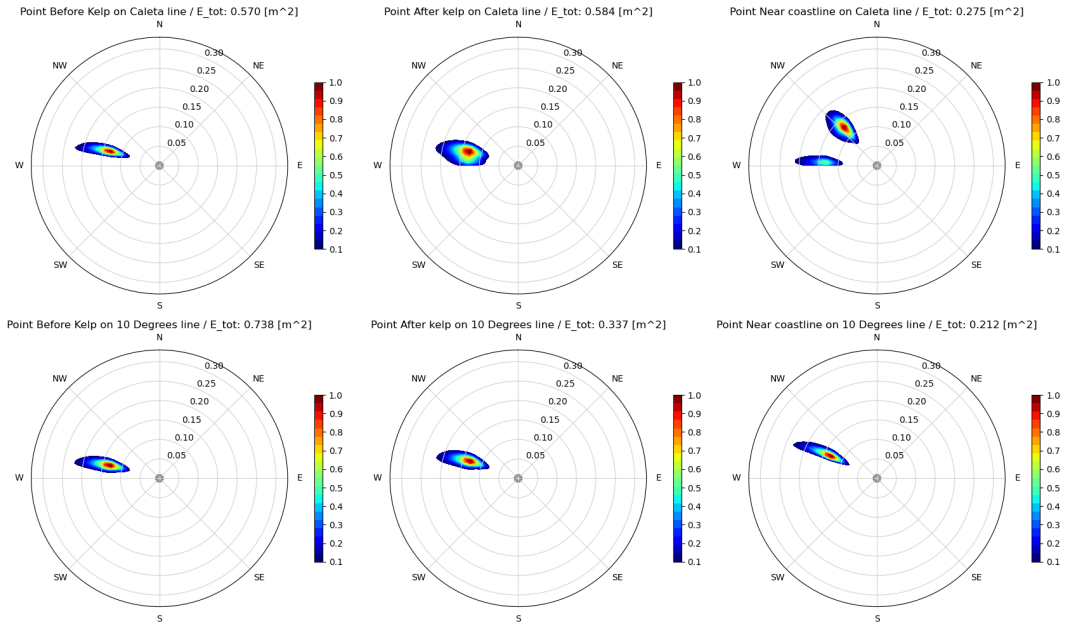

Figure J.23: Energy Density Spectrum of Run 12 over all directions

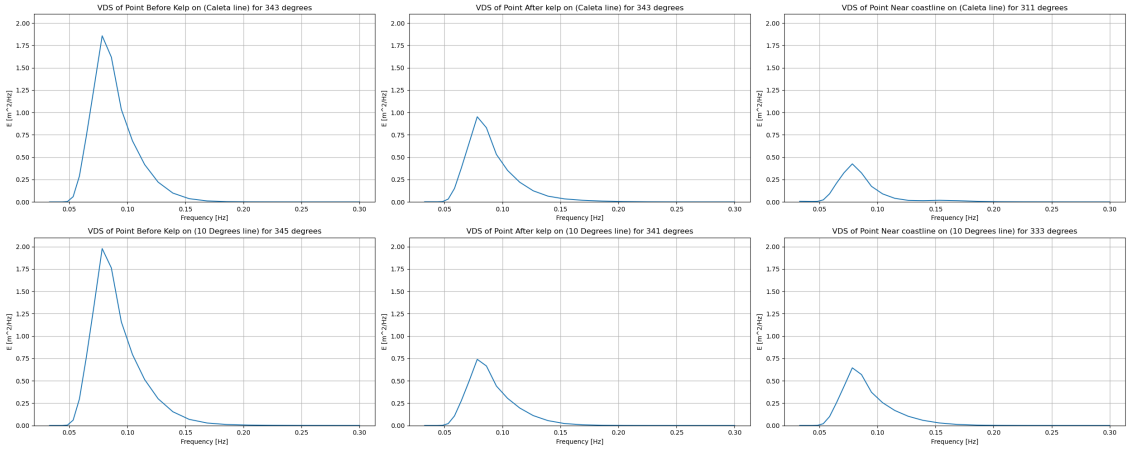

Figure J.24: Energy Density Spectrum of Run 12 in the most Energetic direction

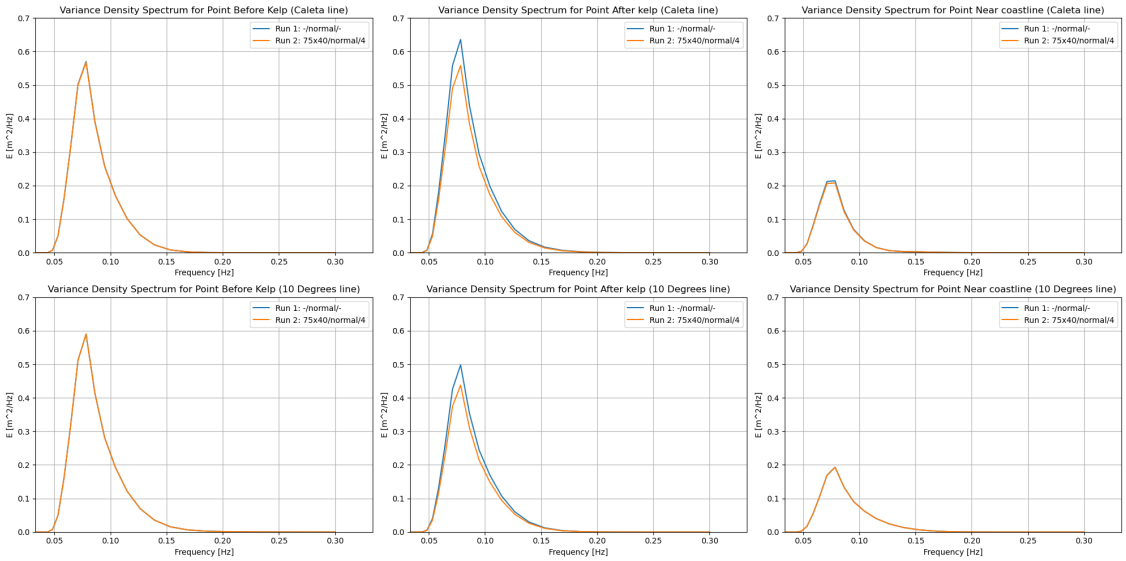

Figure J.25: Energy Density Spectrum of Run 1 and 2

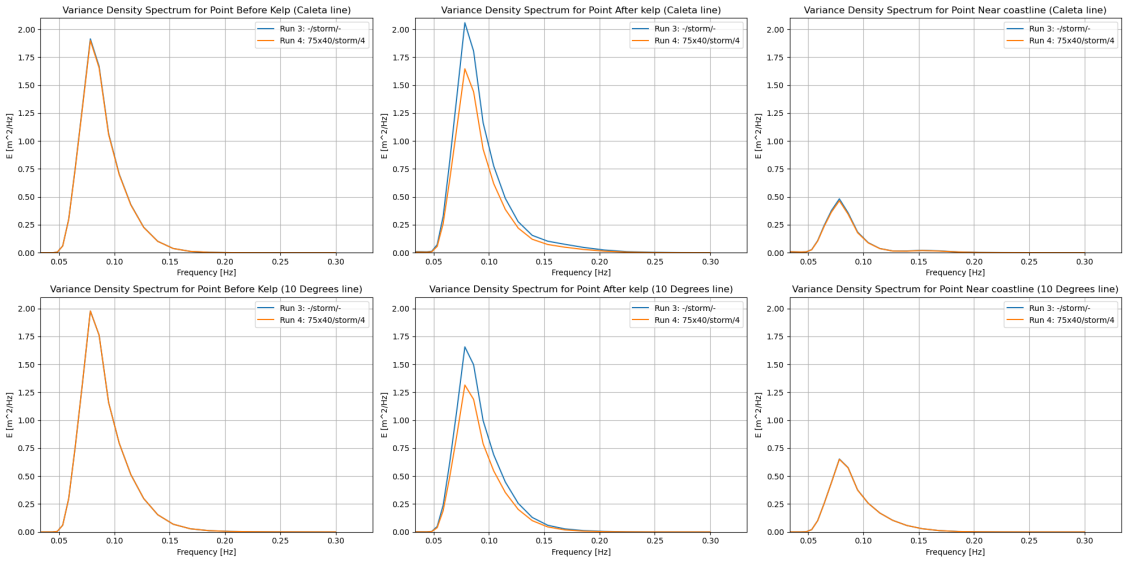

Figure J.26: Energy Density Spectrum of Run 3 and 4

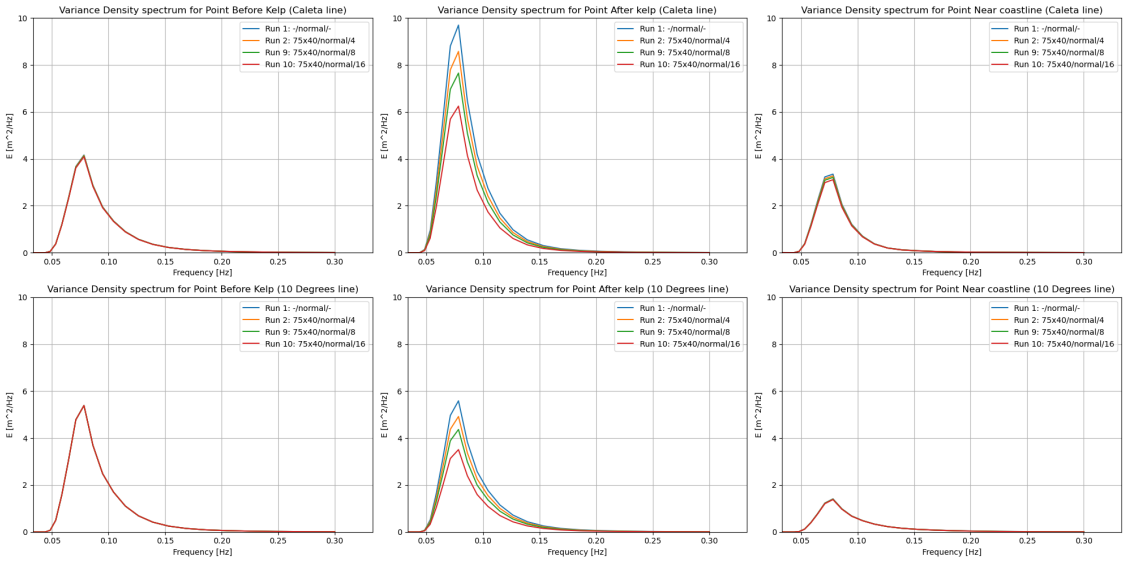

Figure J.27: Energy Density Spectrum testing the density under normal conditions

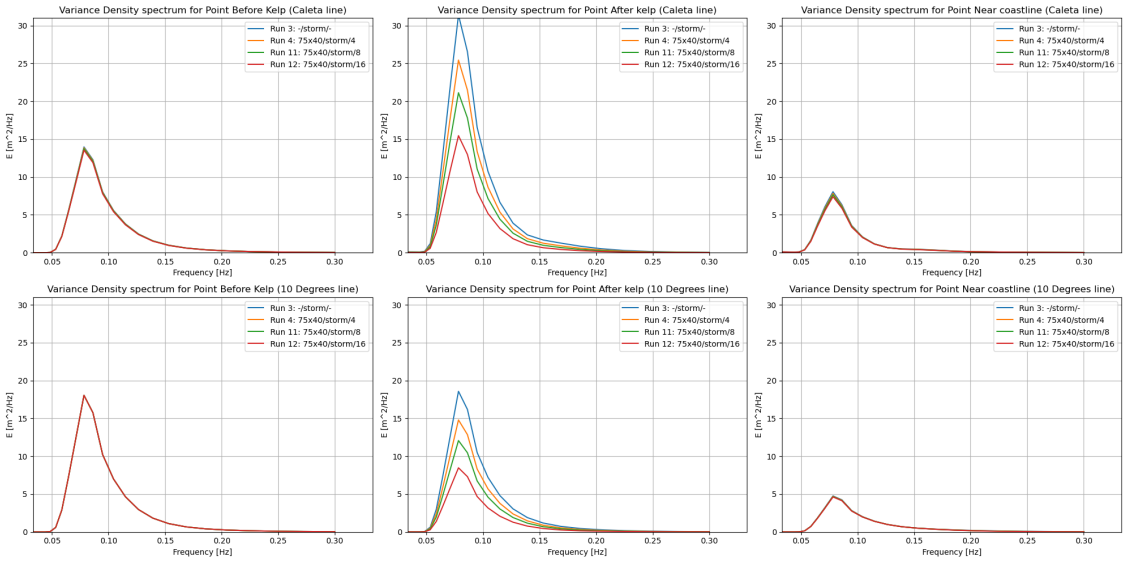

Figure J.28: Energy Density Spectrum testing the density under storm conditions

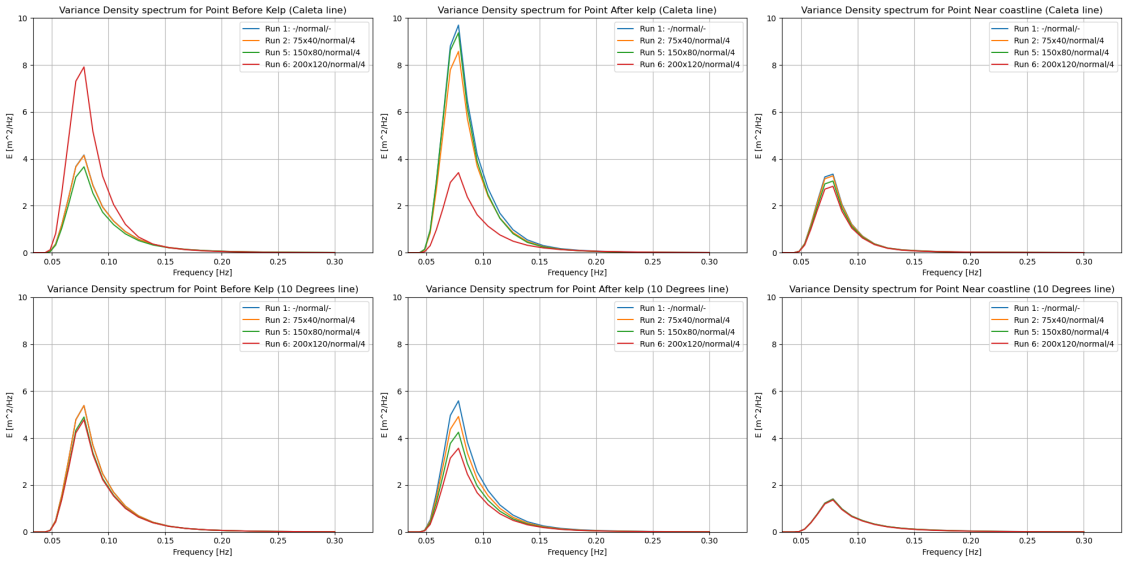

Figure J.29: Energy Density Spectrum testing the area's size under normal conditions

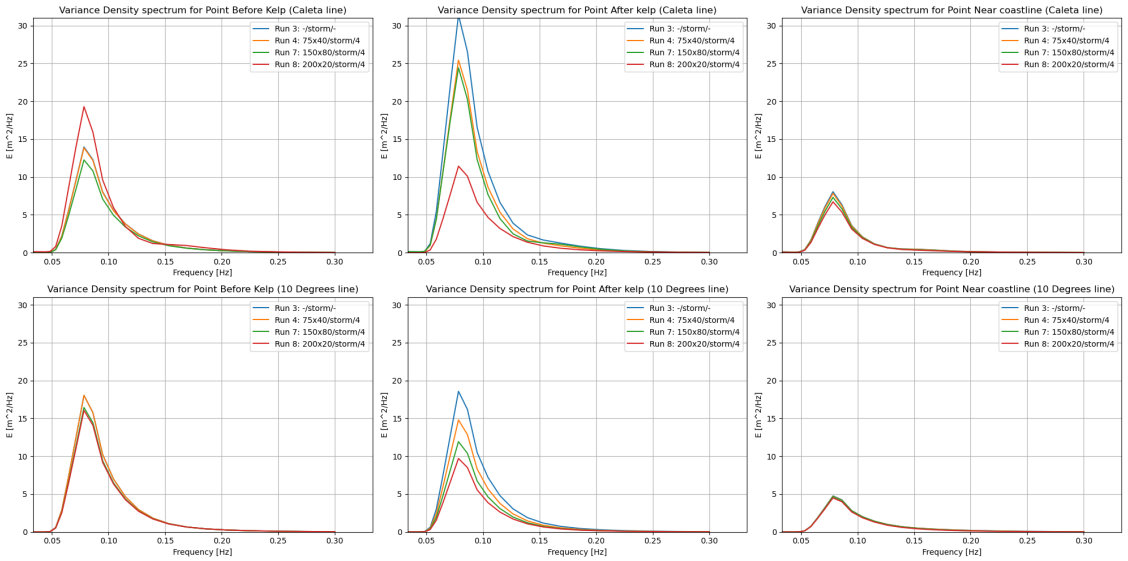

Figure J.30: Energy Density Spectrum testing the area's size under storm conditions

K

Significant wave heights 1D runs

This Appendix contains the significant wave height development of all 4 1D runs.

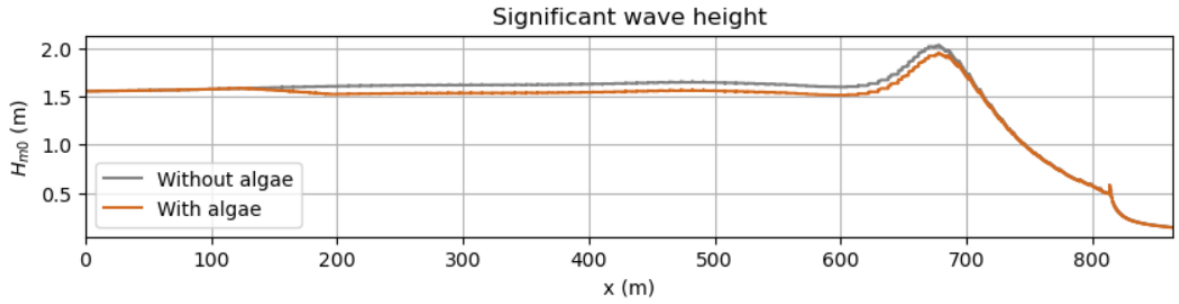

Figure K.1: Significant wave height development of run 1 (Caleta - normal conditions)

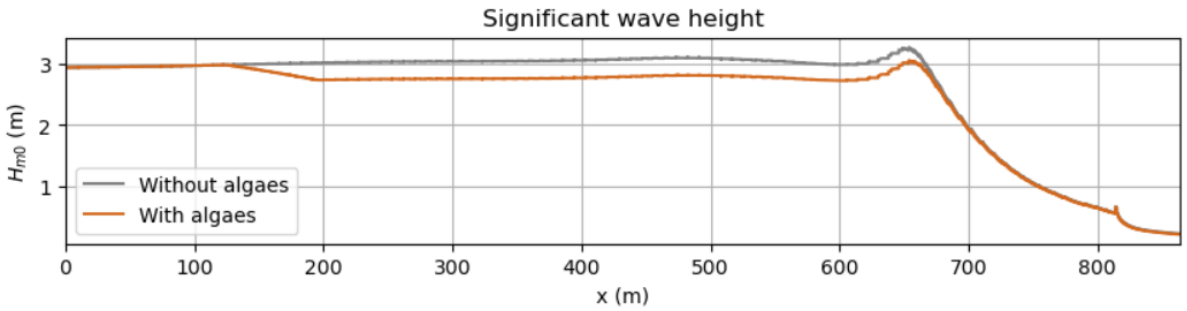

Figure K.2: Significant wave height development of run 2 (Caleta - storm conditions)

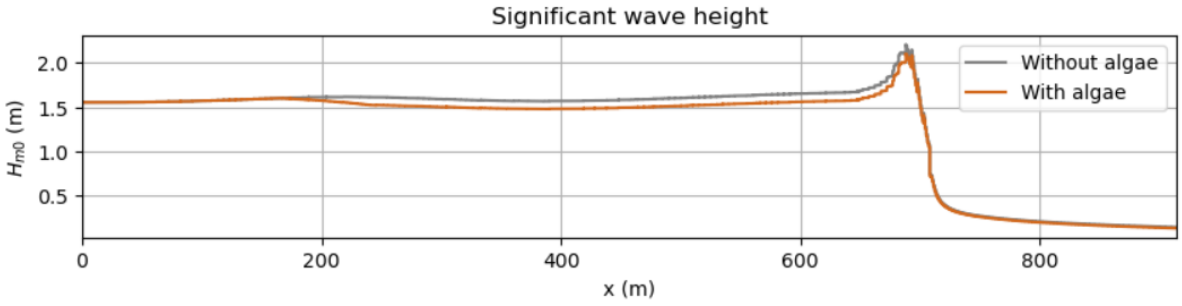

Figure K.3: Significant wave height development of run 3 (10 [°] - normal conditions)

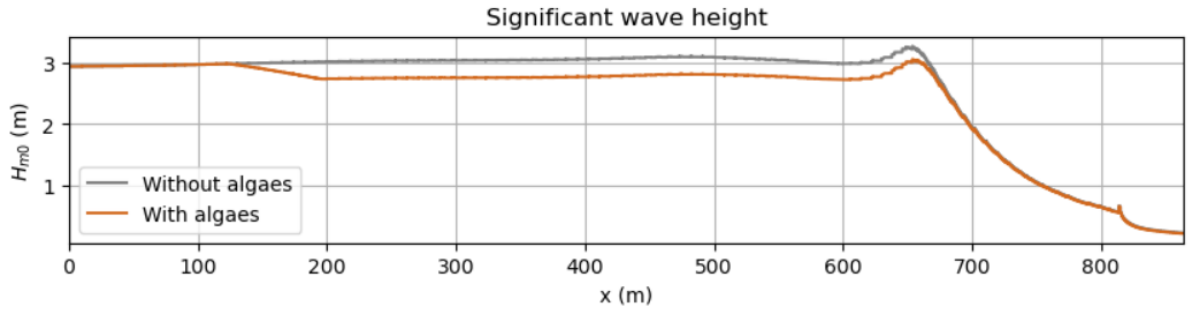

Figure K.4: Significant wave height development of run 4 (10 [°] - storm conditions)