Delft University of Technology
Multidisciplinary project

COASTAL SEAWEED SOLUTIONS

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Abstract

In recent years, strange phenomena occurred in the Caribbean, Gulf of Mexico and West Africa: a massive tide of sargassum, brown algae, washed ashore causing considerable damage to the local economy and environment. The sargassum mostly consists of *Sargassum Natans* and *Sargassum Fluitans*. Old studies concluded that the sargassum came from the Sargasso Sea, however the most recent massive tide of sargassum (named as golden tide) came from an area north of the Amazon river delta. Texas A&M University of Galveston and the University of Florida developed detection systems in cooperation with NASAs satellite images. With the detection system it is possible to track, trace and make forecasts of sargassum landings. Hereby it is possible to act a few days before the sargassum washes ashore, instead of reacting when it landed on the beach already. Most of the problems occur when the massive influxes of sargassum are washed ashore.

Currently, the most used harvesting methods on the beach are by use of rakes and wheelbarrows or by using mechanical equipment like a cane loaders and front-end loaders. The beach cleaning methods causes beach erosion and endangers local wildlife. Therefore, harvesting methods at sea are under development. Sargassum is an organic material and can be an useful source for processing. The most used processing methods of sargassum are burying at the beach or using it as a fertiliser. One of the challenges in processing sargassum is working with the unpredictable appearing character of sargassum.

The known detection methods have been critically analysed and the most favourable method is developed by Texas A&M University Galveston. This system is applicable on other areas as well and it makes forecasts of sargassum landings. The harvesting methods have also been critically analysed and it can be concluded that the most recommended harvesting method has to be done at sea in combination with a floating barrier. Most of the problems are avoided in this manner. For processing multiple opportunities have been pointed out. Biofuel and bioplastics are having large potential. For the mean time using sargassum as a fertiliser is a sufficient solution. The uneven appearances can be solved by drying the sargassum.

Finally, an implementation plan is developed for Quintana Roo to overcome the sargassum problems. It is a step-by-step approach which can be conducted by a party who is willing to take the lead. In this approach the detection system of Texas can be used and new harvesting methods have to be developed. For processing, dry facilities have to be built in order to solve the uneven appearances.

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Introduction

This research project is divided in three parts (A, B and C).

Part A is an extensive problem analysis and describes the characteristics of sargassum and its ecological value. It has been analysed where the massive tides of sargassum, so-called golden tides, are coming from and what the quantities are. The wind and ocean currents determine the pattern of movement of sargassum. The most problems occur in the tourist industry, fisheries and ecology. Also, three studies have been done in order to understand the current plan of approach. This includes current detection methods, current harvesting methods and processing methods for when sargassum is harvested.

In Part B the current detection and harvesting methods have been evaluated. It could be concluded that the current harvesting and processing methods are not sufficient enough, therefore new ideas for harvesting and processing have been presented as well. Eventually, all methods have been criticised in a multi criteria analysis in order to define the method with the best potential. The aim of this research is to improve the situation for countries without a detection system, harvesting method or processing method.

In Quintana Roo, a party that has the overview and is in charge of handling the situation, is missing. Therefore, part C reviews a step-by-step strategic approach for a company that can take the lead in the preparation for a coming golden tide. Further research has to be done, stakeholders need to be involved, investments have to be made and products have to be developed. This step-by-step approach is divided into three phases, where phase 1 can be started direclty. Phase 2 contains an advice in a chosen pilot location. Phase 3 is the final stage where a working detection, harvesting and processing method is provided for the touristic parts of the coast of Quintana Roo. 'Part C' is ended with a roadmap of the implementation plan to visualise an overview of the steps to be taken.

Part A

In the last years the so-called golden tides were present in the Caribbean Sea and the Gulf of Mexico. The sargassum inundated the beaches and caused many problems, especially in the tourist industry. In 'Part A', an extensive problem analysis is given. It is described what the characteristics of sargassum are and its ecological value is explained. The current and wind systems determine the pattern of movement of sargassum in the oceans. Therefore, these systems are analysed in order to know where the sargassum is coming from and how it washes ashore.

The sargassum problem is divided into three different studies in this project. First, the current detection methods of sargassum are analysed. Two universities of the United States are using NASA satellite images to detect sargassum, where any other country in the Caribbean Sea does not have a proper detection system at all. Secondly, once the sargassum washes ashore, it has to be harvested. The beach harvesting causes beach erosion. Therefore, harvest methods at sea are studied as well. Finally, the different processing methods are studied.

In 'Part B' the detection and harvesting methods are criticised in order to find the best working methods. Also, multiple processing opportunities are mentioned. With these results an implementation plan can be made for Quintana Roo in 'Part C'.

Chapter 1

Problem definition

The last recent years there was a major influx of sargassum that washed ashore on the beaches along the Gulf of Mexico and the Caribbean Sea, this phenomenom caused many problems. In section 1.1, the characteristics and ecological value of sargassum will be described. To understand where the sargassum originates from, the source and movement patterns have been studied in section 1.2. Section 1.3 and 1.4 the quantities of sargassum and its problems have been discussed.

1.1 Sargassum

1.1.1 Characteristics

The sargassum that has caused problems in Mexico is a mixture of two different species of floating brown algea;

- *Sargassum Natans*

- *Sargassum Fluitans*

The exact ratio of the two species depends on the geological location. In the Sargasso Sea the mixture consists mostly of *Sargassum Natans*, while in most coastal waters there are more

Sargassum Fluitans.

Both species are composed of leafy appendages, branches, and round, berry-like structures. These berries are small air-chambers, called pneumatocysts, which are filled mostly with oxygen. Pneumatocysts add buoyancy to the plant structure allowing it to float on the surface. The name sargassum comes from the Portuguese word for little grapes, sargaço. During one of Columbus journeys it was the first time that large rafts of floating seaweed were reported.

Sargassum seems to reproduce itself by vegetative reproduction. Seaweed cells are totipotent and any fragment of a brown algae can regenerate an entirely functioning plant.

When sargassum plants age, they lose their buoyancy and sink to the seafloor. There, they will provide energy in the form of carbon to fishes and invertebrates.

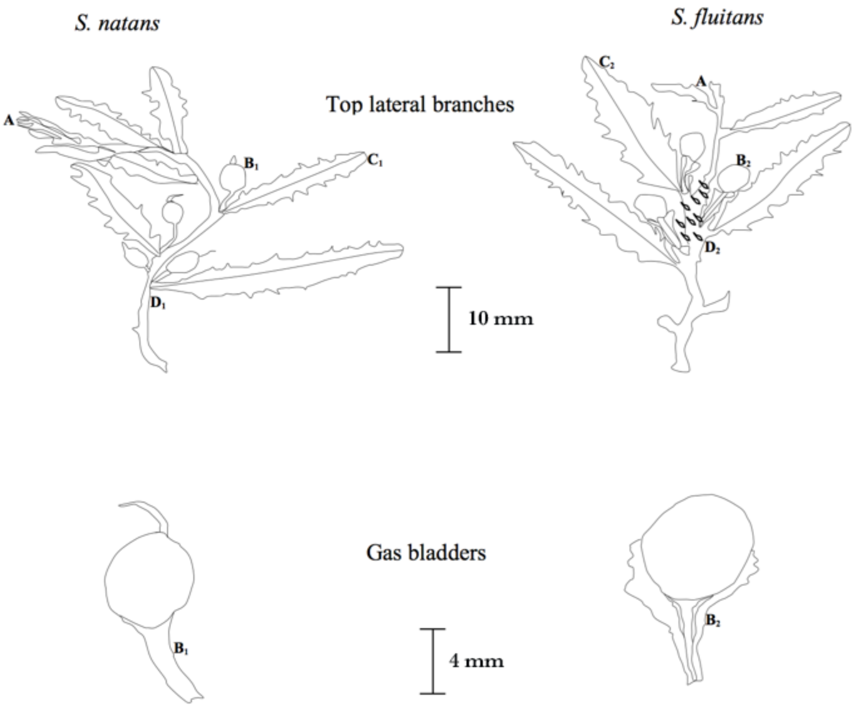

Figure 1.1: Sargassum (*S. Natans* and *S. Fluitans.* Receptacle (A), gas bladder with spine, stalk without wing (B1), gas bladder without spine, stalk with wing (B2), linear leaf with seriated margin (C1), lanceolate leaf with seriated margin (C2), lateral branch with spines (D2) (Identification and chemical studies of pelagic masses of Sargassum natans (Linnaeus) Gaillon and *S. Fluitans* (Borgessen) Borgesen (brown algae), found offshore in Ondo State, Nigeria, O. O. Oyesiku1* and A. Egunyomi2)

1.1.2 Ecological value

In the Sargasso Sea there is little sign of life, which creates the impression of a desert in the ocean. But within this desert, drifting with the winds and currents, there are floating mats of sargassum that support a remarkable web of life and give the cause for the Sea its name. Sargassum habitats provide food and protection for a huge number of juvenile fishes, some of which are commercially important species. Young sea turtles hide from predators in the mats and eat the algae and other creatures that live in it. Over 100 species of fish spawn in the Sargasso Sea and the mats shelter larval forms of many species. Next to that, more than 150 invertebrates are found in the sargassum and there are ten species endemic to the environment [12]. In fact, several creatures, like the *Sargassum Fish* (a type of frogfish), are born, reproduce theirselves, and die solely within this environment. The sargassum also holds thousands of eggs. When they hatch, they live among the sargassum until they are big enough to venture the open ocean.

The mats of sargassum are also important hunting areas, attracting pelagic fish that feed on the smaller fish sheltering below the weed. Sea birds are also hunting on the animals in the sargassum to feed their young. The approach towards land, marks the beginning of the end for sargassum and thereby the species that live in it. By the time it washes on the beaches the sargassum has already been stripped on most of its passengers. But even when its drying in the sun, the important role of sargassum is not over. Eventually, sargassum will mix up with the sand and thereby stabilising the beaches. Onshore, it is alos a source of food for crabs, insects and many tiny creatures, which in turn feed shorebirds and other coastal animals [30].

Because of its ecological importance, sargassum has been designated as Essential Fish Habitat, which affords these areas special protection. However, the sargassum habitat has been poorly studied because it is so difficult to sample. Further research is needed to understand, protect, and best conserve this natural resource.

1.2 Source and movement

In this subsection the source and movement of the sargassum will be explained. To understand the movement patterns, the current and wind systems should be researched. In the used literature two main sources and movement patterns have been found, these will be discussed in paragraph 1.2.2. Hereafter, it is analysed how sargassum washes ashore (paragraph 1.2.4). This is based on wave theory.

1.2.1 Current and wind systems

Current systems

Because sargassum floats in and on the water, oceanic currents are largely defining its paths. Therefore these currents have been sketched schematically to get a basic understanding. The systems in the Sargasso Sea will be treated first, secondly the systems in the Caribbean Sea and at last the systems in the Gulf of Mexico will be discussed.

The Sargasso Sea is known for its still waters and dense seaweed accumulations. However, there are strong oceanic currents in the Sargasso Sea that can play a dominant role in the sargassum transport. The North Atlantic Gyre characterises the current pattern in the Sargasso Sea. The North Atlantic Gyre is a circular system of ocean currents that is located on the northern hemisphere in the Atlantic Sea. The currents that compose the North Atlantic Gyre include the Gulf Stream, the North Atlantic Current, the Canary Current and the Atlantic North Equatorial Current, see Figure 1.2. The North Atlantic Gyre experiences, as many other oceanographic patterns, seasonally variability. It expands in east-west direction and thins in north-south direction during the Northern Hemisphere winter season. However, the volume transport does not change significantly over time. From winter to summer the gyre shifts southwards (a few degrees latitude).

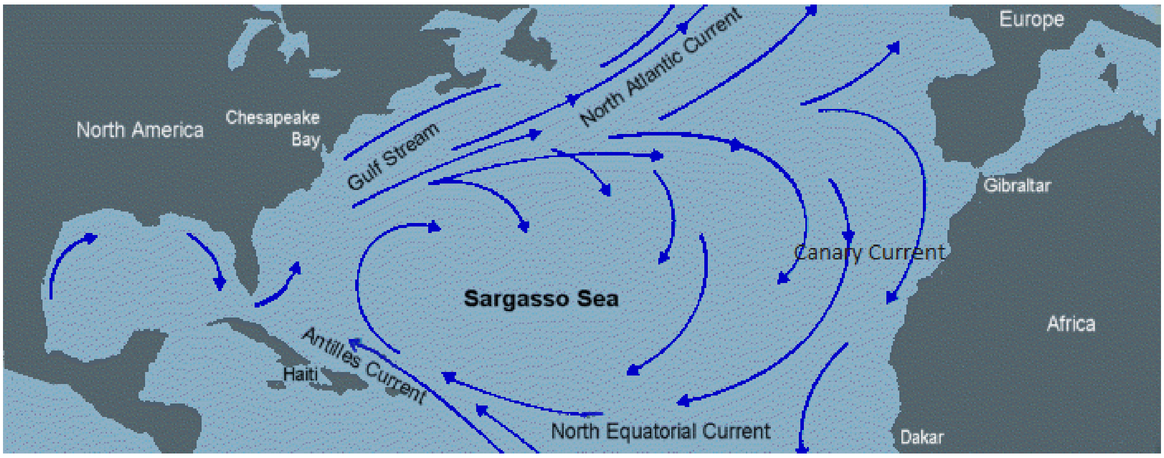

Figure 1.2: The Sargasso Sea with its ocean currents

North Equatorial Currents are also flowing into the Caribbean sea. They propagate in the west ward direction south of Puerto Rico, Dominican Republic and Cuba towards the Yucatan Channel. South of the main current, several counter clockwise eddies are formed, see figure 1.3.

Figure 1.3: The Caribbean Sea with its ocean currents

As the currents flow from south to north into the Caribbean sea, they subsequently enter the Yucatan channel (between Yucatan peninsula and Cuba). This forms the Gulf Loop Current, which curves east south along the coast of Florida and exits the Gulf of Mexico in the Florida Straits [26]. A part of the water that entered the Yucatan channel breaks away from the main current and forms eddies that will direct westward. Meanwhile in the shallower parts, the wind driven currents are traveling along Louisiana, Texas and Mexico.

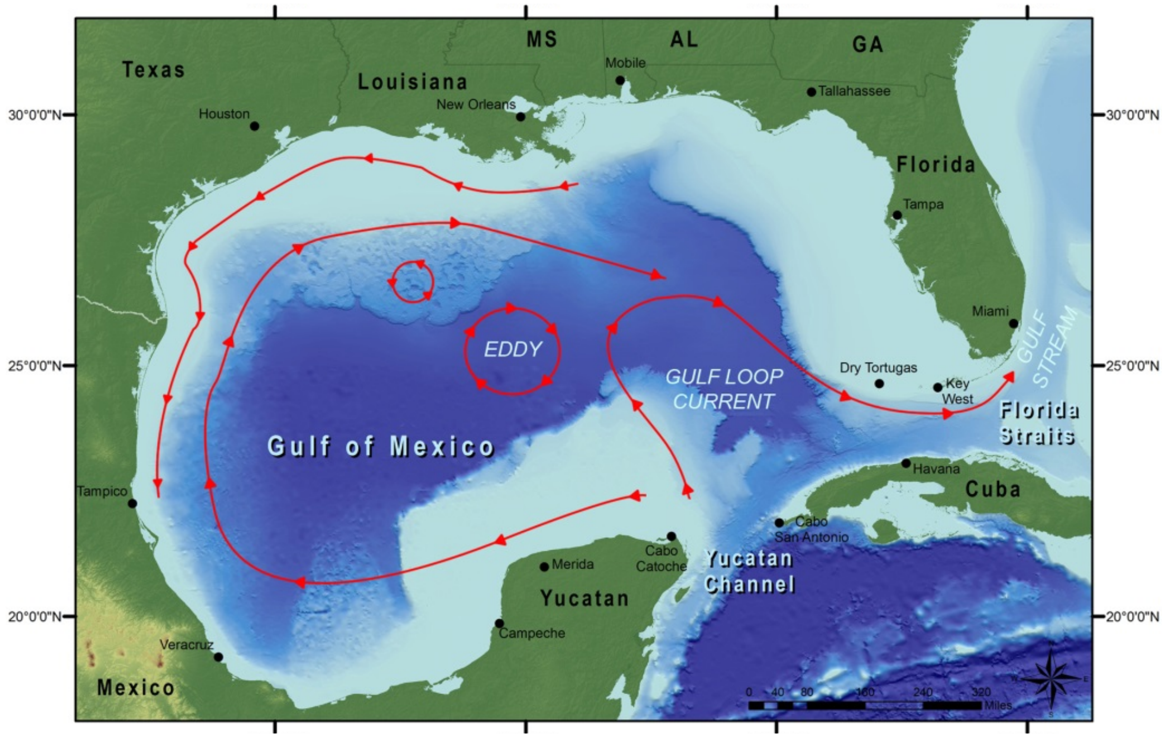

Figure 1.4: The Gulf of Mexico with its currents

Wind systems

Because sargassum floats on the water surface, wind has an impact on the transportation. Figure 1.5 distinguishes the wind patterns in January and July. There are some similarities for both periods in the Gulf of Mexico and the Caribbean sea because the dominant wind is coming from the east over the Atlantic. However, some differences can be noted. In January, the wind pattern over South-America is directed southwards and in July it is directed northwards. In July a circular pattern can be noted over the Atlantic, which is not visible in January. These zonal wind systems are determined by large-scale pressure belts as a result of latitude dependent heating of the earth surface. For the 10-30° the moderate trade winds are present.

The Azores High Pressure System is a high atmospheric pressure region typically found south of the Azores in the Atlantic Ocean. In summer, the high pressure is centered near Bermuda (Bermuda-High), creating a warm southwest flow towards the east of the United States. In winter, the conditions are more variable. Global warming researchers suggest that it may be intensifying the Bermuda High in some years. However, during the Norhtern hemisphere winter of 2009-2010, the Azores High was smaller. The region was displaced to the northeast and weaker than usual, allowing sea surface temperatures in the Central Atlantic to increase quickly.

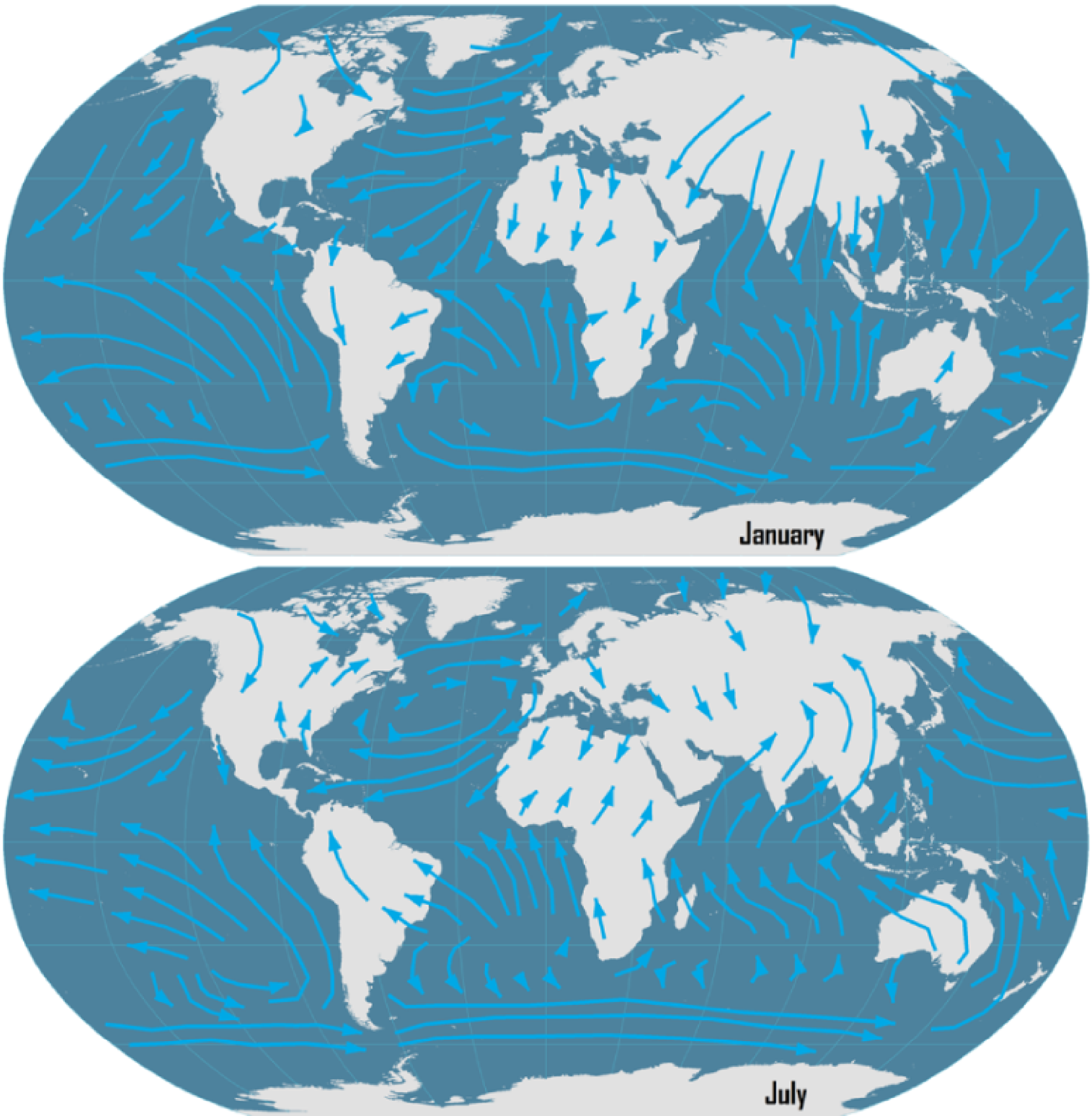

Figure 1.5: Wind systems on earth

1.2.2 Two movement pattern theories

The Sargasso Sea as source

Several studies show that a consistent pattern of movement is discernible. The Sargassum Early Advisory System (SEAS) is designed to give coastal managers warnings about the sargassum landings, allowing them to adjust their allocation of resources, see section 2.2. Webster and his research team at SEAS found the Sargassum Loop System [29].

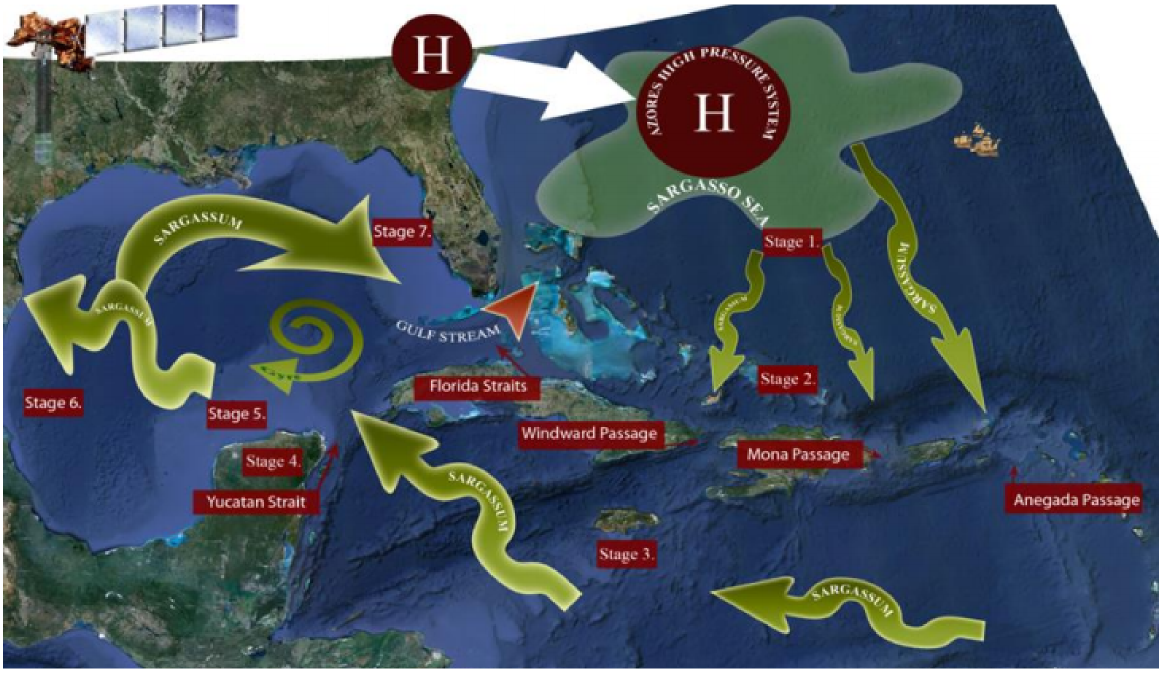

Figure 1.6: Sargassum movement with the Sargasso Sea as source

The loop system is initiated by the wind circulation of the Azores High Pressure System pushing large slicks of sargassum from the Sargasso Sea (Stage 1). According to an imagery analysis by SEAS, the Atlantic Ocean had to be included in the sargassum movement studies. It has been proven that the sargassum drifts through the Caribbean Sea into the Gulf of Mexico (Stage 2). Azores high-pressure system represents the initial energy required to send pulses of sargassum into the Caribbean Current (Stage 3). Sargassum enters in the Gulf of Mexico through the Yucatan Strait by flowing with the surface currents (Stage 4). Periodically, a gyre will break off from the Gulf Stream (Stage 5). The gyre can drift westwards and with favourable currents the coasts of North Mexico and South Texas can be reached (Stage 6). Sargassum that does not make landfall eventually will return to the Gulf Stream, leaving the Gulf of Mexico, and entering the Sargasso Sea again (Stage 7). These different stages correlate consistently with a year to year pattern of movement, corresponding to prevailing surface currents and wind movements [2].

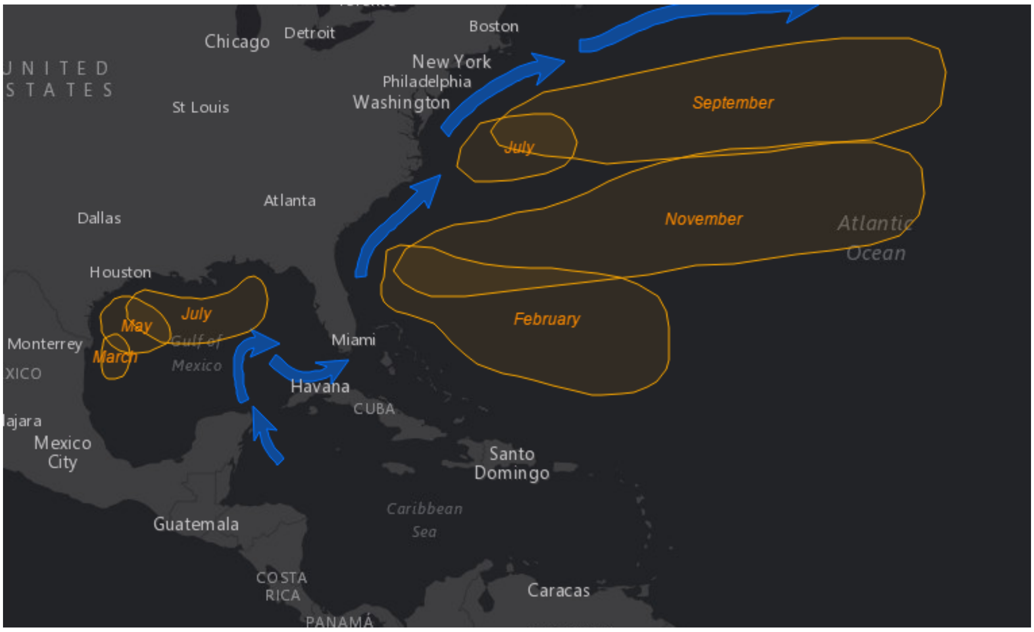

Figure 1.7: The monthly movement of sargassum from the Gulf of Mexico into the Sargasso Sea

The area north of the Amazon river as source

In some years the sargassum production is much higher then usual (see paragraph 1.3.1). For example in 2011, this was the year of the great sargassum pileup. Major amounts of sargassum landed on the Caribbean and African coast of the Atlantic [2].

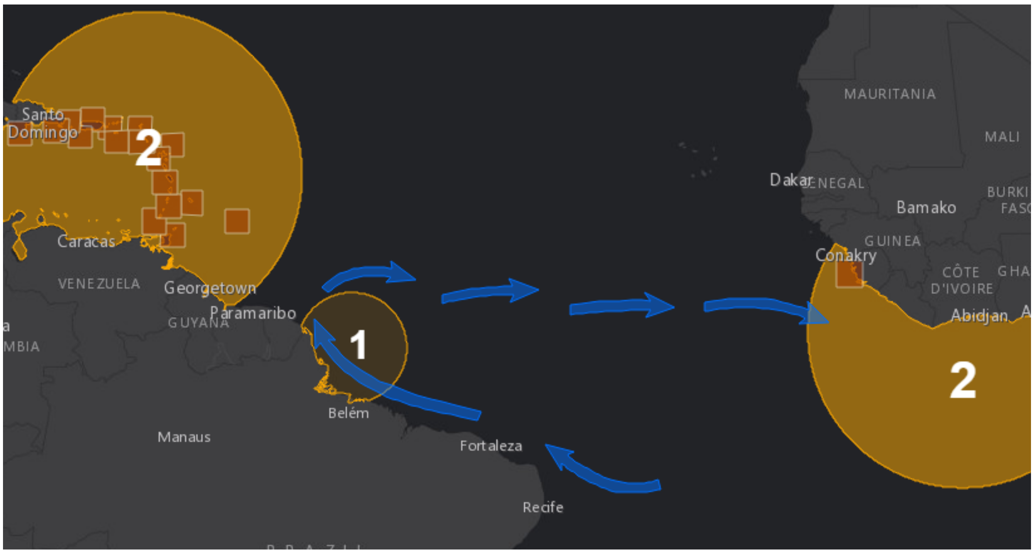

Figure 1.8: Sargassum movement with the area North of the Amazon river as source

It Figure 1.8, it can be seen from that the source of sargassum was not the Gulf of Mexico, as first was thought. Instead, research from Gower declared that the sargassum originated in the region offshore Brazil near the mouth of the Amazon river with a high-nutrient content

[20]. The underlying causes of this event have not yet been elucidated. In section 1.3, possible explanations for those large amounts are described. During this period, the sargassum never reached the Gulf Stream, hence it was not transported to the Sargasso Sea region where it normally accumulates in the summer. Instead it circulated northwards from the coast of Brazil and bloomed in the North Equatorial Recirculation Region (NERR). The NERR region extends from the equator to the seasonally forming North Equatorial Counter Current at approximately 5 - 10 °N and from Brazil to Africa. In 2011 it was flushed out of this region. The unprecedented volumes washed ashore in the Caribbean. The part that did not land drifted eastward to West Africa, where it washed ashore on the beaches in Sierra Leone, Liberia, Ivory Coast and Benin. In 2015 a similar event with the same magnitude to the 2011 event have been observed.

1.2.3 Movement discussion

The first movement pattern theory is mostly in accordance with the ocean currents discussed in paragraph 1.2.1. Except for stage 1 where the sargassum supposed to go from the Sargasso Sea into the Caribbean Sea. Examining the standard wind or current patterns this does not add up. However, it was said that the Azores High Pressure system is pushing the sargassum slacks south. According to the used literature this makes sense for the month of January.

The second movement pattern lies more south than the wind or wave patterns. This pattern of movement can be explained because the Equatorial Counter Current is not treated, which flows from west to east at about 3-10°N. The strength of the Atlantic Equatorial Counter Current is notably stronger in years following El Niño in the tropical Pacific.

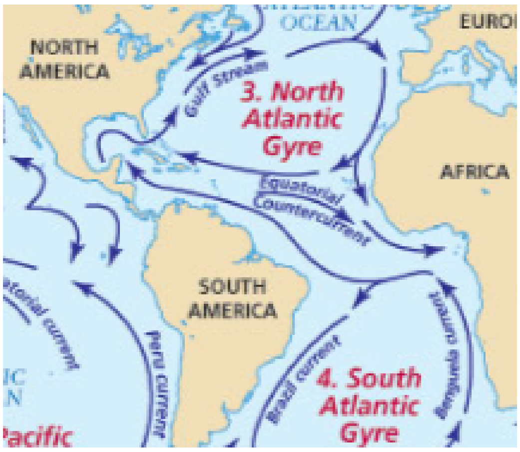

Figure 1.9: The North Equatorial Counter Current

1.2.4 Sargassum washing ashore

In the end, only a part of sargassum will wash ashore. It is interesting to look at which factors play a role for the landing once the sargassum is floating near the coast. As explained before, wave factors contribute to the movement of sargassum. In this paragraph some important wave factors will be outlined. This will create a better understanding in why sarggasum washes ashore.

Propagating waves carry wave momentum across the ocean surface. Momentum is the product of mass density and velocity. Between the trough and the crest it creates an onshore wave movement. This onshore wave movement is compensated by the return current in the lower and middle part of the water column closer to the shore. The return current is offshore directed and increases in magnitude moving landwards. At the bottom small onshore directed velocities are present, which are called the Long-Higgings streaming [4]. The figure below sketches this theory.

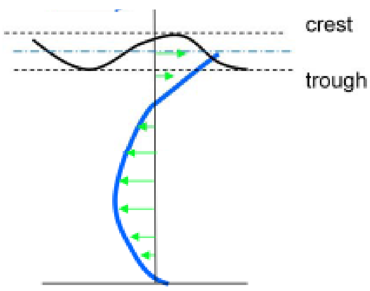

Figure 1.10: Forces in a wave sketched

The floating sargassum experiences an onshore movement. Sargassum can get too heavy or less buoyant and sink, consequently will experience an offshore movement. When it sinks to the bottom, it is questionable if it will stay in place or not, since the velocities are very low.

For the theory discussed above, an alongshore uniform coast with parallel depth contours is assumed. In reality this is not the case, since sandy shoals are present on beaches and structures like ports and breakwaters do not contribute to a straight coastline. Hereby, rip currents can be formed. A rip channel is an offshore directed flow from the beach. Many experiences are done which floating drifters in rip channels. These drifters floated offshore in the rip channel. It is logical that this also holds for sargassum in a rip channel.

On sea with a specific blend of wind and wave movement sargassum floats in a linear pattern on the water surface, the same as those foamy streaks of scum in harbours. This is due to the Langmuir circulation [27], see a more detailed explanation in appendix A.1.

1.3 Quantity

The quantity of sargassum fluctuates over the year. In the Gulf of Mexico the highest concentrations indicated by satellites in the previous years are in the period of May till July, while in a broad range from the Atlantic to the east of Cape Hateras the largest amounts can be found in July and August [13].

By tracking the sargassum, a consistent pattern of movement from year to year has been found. From March to June the Gulf of Mexico acts as a nursery. From here a part of the sargassum, with an estimated biomass of one million ton wet weight each year, is transported to the Sargasso Sea. During the summer the sargassum accumulates, which results in giant sargassum mats that coalesce into continuous features extending over hundreds of kilometres. In the winter the sargassum dies of and will be replenished upcoming year again. `http://grid-arendal.maps.arcgis.com/apps/MapJournal/index.html?appid=f616ec1db45f4e898970bd448b190f50`

1.3.1 Golden tides

Under normal conditions, only small amounts of sargassum are washing ashore. In these small quantities sargassum does not cause nuisances and has an ecological value and protects the beach from erosion. But periodically, the volume of floating sargassum increases. To describe massive sargassum shoaling events, the term golden tide is introduced. Golden tides are unprecedented peak periods where the sargassum pollutes beaches with along coming consequences. Events like this have occurred in history as well, but in the last 10-15 years a growth has been noticed.

Figure 1.11: Golden tide

The amounts sargassum on the beach started to increase along the coasts between the Gulf of Mexico and Bermuda last decades. In 2005 very atypical amounts of sargassum were found in the Gulf of Mexico, see figure 1.12 [14]. The quantities were so large that this year was titled as sargassum year. During 2011, the anomalous amount of sargassum biomass in the Atlantic at its peak was a 200-fold of the average recorded in the previous 8-years. It extended to the North-West African coast where it was never noticed before. Similar events occurred in 2014 and were recorded on the Caribbean Coast and along the coastline of the Gulf of Mexico. This beaching of the huge masses of sargassum did not stop during 2015 [5]. The sargassum on the beaches could have built up to depths of more than 2 metres.

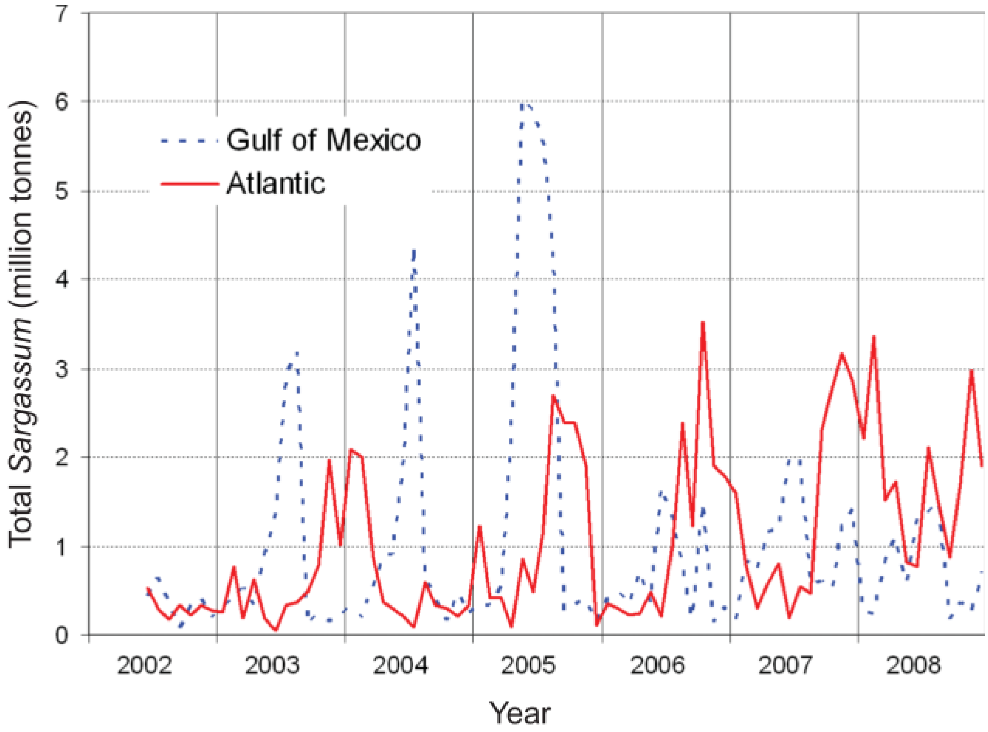

Figure 1.12: Total quantity sargassum (wet weight)

During the golden tide in 2014-2015, 8,400 tons of sargassum washed ashore in a single day on a stretch of less than 5 kilometres was recorded in Galveston (Texas, USA). This was the highest count measured so far [11]. In the same year, Galveston Island, with a length of around 43,5 km, received nearly 50,000 tons of sargassum in one season. Also the 10 kilometres long beaches near Cancún (Quintana Roo, Mexico) suffered under large quantities of sargassum in the period of March till June [28].

Under normal conditions the measured amount of harvested sargassum (wet weight, including sand) per meter beach per day in Quintana Roo will be between 0 and 10 kilogram. While during a golden tide measurements turned out to be a plurality of those numbers, up to 300 kg per meter beach per day. (Appendix A.2)

1.3.2 Possible causes

While the golden tides of 1980s and 1990s in the Gulf were explained by the later described high nutrient loads of the Mississippi river, other explanations for the latest golden tides are considered as well. Some scientists link global warming to the increasing sargassum washing ashore. They associate the causes of it with the higher temperatures and low winds which influences the sea currents [8].

Another explanation for the new paths the sargassum is following are the El Niño and La Niña wind phenomena. El Niño is a warming of the Pacific around the equator, La Niña the opposite, causing affects on the global climate and disrupting normal weather patterns. Possible consequences are different surface water movements, declared by the interaction with the strong winds and wave action. [21]

Finally cold fronts are mentioned as a possible cause for the different sargassum paths. Cold fronts are shifts from the southerly winds to a northerly based wind which pushes cold air masses to the Gulf of Mexico. This change in wind pathern can drive the sargassum out of its normal circulation, but no proofs are available yet [17].

As a contributing factor to the unusual sargassum quantities, the BP oil spill on the Gulf of Mexico in 2010 is cited. Large measures were needed to absorb the large floating oil slicks. One of those measures was using nitrogen and phosphorous-based dispersants. Products like these break up oil, but also causes very high abundance of nutrients within the water chemistry. Those high nutrient loads works as fertilizer for seaweed and enforces the growth of sargassum [21].

1.4 Problem

Although sargassum belongs in certain regions and is important for the ecological system as explained in section 1.1, sargassum can have many different negative impacts. This section will explain those negative sides and mention the challenges in finding a suitable solution.

In normal quantities sargassum contributes to the natural system and is not considered as a problem. Once it arrives in massive influxes it becomes a serious problem. The large sargassum rafts on the water can imped fishing and other vessels at the sea. It can impact the catching of key fish species and disrupt fishing communities, sea turtle nesting and tourism activities.

1.4.1 Tourism

Stranded sargassum will lead to beach fouling and reduce the attractiveness significantly, even more if it is entrapped with other non-ecological waste. The several metres high build ups on the beach during the golden tides will limit swimming and access to nearshore boat moorings and harbours. As it floats near the coast, the sargassum can collect small plants and animals that attach and grow on the blades of algae. Attached insects can sting people. But the major complaint on touristic places is the very unpleasant smell the decaying sargassum has together with the large number of flies it attracts, when it is trapped in heaps along the shoreline unable to dry out [1]. The smell causes nausea, tearing of the eyes, headaches and loss of sleep. If events like the golden tides happen more often without a good approach, tourism can decline significantly.

1.4.2 Oxygen concentration

When sargassum is floating in big rafts near the coast, the rafts are blocking sunlight for seagrass at the bottom of the sea. This sunblocking reduces the photosynthesis process and so reduces the oxygen production. Besides decaying sargassum will use extra oxygen. Those two factors together will drastically reduce the oxygen concentration in the seawater resulting in hypoxia (oxygen deficiency) or even anoxia (oxygen deprived). Under those circumstances seagrass and other marine plants will die, animals have to flee. Especially dying seagrass is a big problem, while seagrass is holding the beaches together with its roots. Without the seagrass beach erosion will easily occur. It will takes up to hundreds of years for the seagrass to recover.

1.4.3 Ecosystem

Decaying sargassum in the waterline will result in unaesthetically brown plumes in the water, which are a threat to the health of critical ecosystems. Turtles are entangled in the sargassum and will drown. Among others coral reefs will suffer due to the low oxygen content and high level of nutrients. Next to this there is a build-up of poisonous hydrogen sulphide gas, which is harmful to most marine animals [1].

1.4.4 Fishers

The sargassum impact will not have the same affect on a particular location throughout the season. This means that some locations are affected less and others more by the sargassum. Consequently, the less affected areas are more prone to over-fishing, including juvenile fish. The less affected harbours are more crowded, because fishers prefer to dock their boats in those harbours. Besides the fish, the fishing gear and motors can get trapped in the sargassum as well and oars could get stuck.

1.5 Challenges

On many locations with those conditions the massive sargassum amounts are considered as a disaster. Fish kills, entanglement and drowning of adult turtles, beach loss and significant disruption of tourism and fishing sectors are witnessed. There are several factors which has to be considered finding a solution for the sargassum nuisance on beaches.

1.5.1 Detection

While under normal conditions, no problems will occur, it is clear that the golden tides as they appeared before will come again. Once it occurs, it is the challenge to be prepared and to ease the negative impacts of the sargassum nuisance. Better detection and forecasting methods have to invented to achieve this.

1.5.2 Harvesting

Cleaning needs to be done without over-sanitizing the beaches. Too much cleaning will yield beaches that look like groomed ski runs and are terrible for bird life, sea turtle nesting and damaging to dune vegetation. There are some cases where beach cleaning is done by heavy machinery. Apart from taking away the sargassum, lots of sand are removed, resulting in beach erosion. Also dunes, which are essential for coastal protection and nesting habitat, can be damaged by this kind of equipment.

1.5.3 Processing

Once the sargassum is harvested, most of it is dumped and burned. Just some of it is used for processing. During the golden tide a lot of the sargassum is harvested. Therefore, it's a challenge to find proper processing methods for these large amounts.

Chapter 2

Current detection methods

In many countries the detection system can be improved significantly, because it does not work properly, see section 2.1. Howerver, in the United States there are three universities that are doing research on sargassum and its movement. Texas A&M University Galveston is developing a system called Sargassum Early Advisory System, see section 2.2. University of Florida is making satellite images with floating sargassum viewable on Google Earth, see section 2.3. In section 2.4 it is described that the University of Southern Mississippi is collecting reports of the sargassum.

2.1 Reactive systems

In many countries there is no proactive system. This means that sargassum has to wash ashore first before the people come in action, this is called a reactive system. At some places the detection of sargassum is done by some fishers, but these detections are poorly communicated to all the interested stakeholders along the coast. Currently, every stakeholder is taking care of their own problem. Another prediction method is by using Barbados as a reference point. Based on earlier events where Barbados had landfalls, the landfalls occurred on other coasts in the Caribbean Sea as well, only a few weeks later. In short, the detection and forecasting system can be improved a lot.

2.2 Texas A&M University Galveston

Due to the golden tides (see paragraph 1.3.1) people started investing in systems to predict the arrivals of the seaweed. In order to provide coastal managers with an early advisory system, scientists and managers cooperated at the Galveston faculty of the Texas A&M University and developed a proactive strategy to replace the former reactive strategy. This new system is named Sargassum Early Advisory System (SEAS) [24].

Historic data sets along the coast of Texas were compiled, using local and coastal newspapers over the last 150 years. The SEAS team enlarged its analysis by including the Atlantic Ocean and the Caribbean Sea and found the Sargassum Loop System (see paragraph 1.2.2).

The university collaborates with NASA, who is providing satellite imagery. Once the satellite imagery detects the sargassum, the direction and speed of the sargassum will be predicted with help of wind and current data. With the Sargassum Predictive Model, the distance towards the shore is calculated. With these 3 steps a sargassum landfall can be predicted. The estimated landfall timeframe is sent to the appropriate beach managers and municipalities. The beach managers and beach cameras can confirm the landing by ground-truthing data (field support and a research vessel that reports the coordinates of sargassum offshore). This confirmation is used as feedback for Sargassum Predictive Model [29]. The system is sketched in the flow chart below.

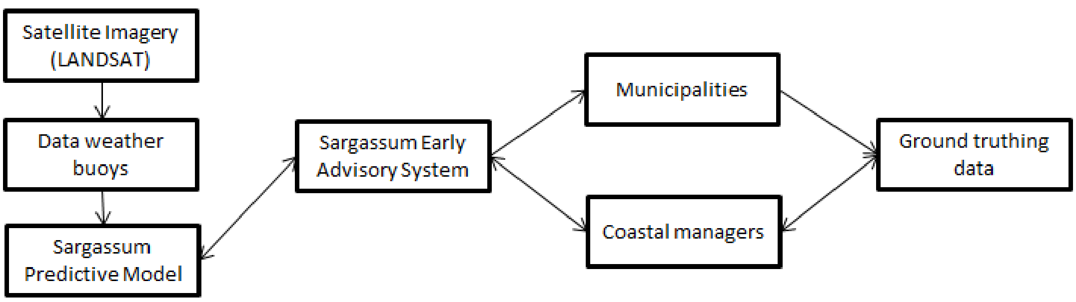

Figure 2.1: Flowchart SEAS

The ground truth locations are situated along the Texas Gulf Coast at three monitoring sectors (the upper coast, the central coast and the lower coast). It stretches from Sabine Pass (at the border of Louisiana) towards South Padre (at the border of Mexico). Between those pints, several beach cameras are installed in order to better track the sargassum movements and landfalls.

SEAS also forecasts for 19 different locations in the Gulf of Mexico and the Caribbean Sea. The figure below depicts where these locations are situated. Every eight days, SEAS is providing them with a forecast, which contains wind, current and net drift data [24]. Also, an additional satellite image is given to observe the sargassum. This forecast is less accurate, since the system along the Texas Coast is full time monitored, contrary to the other locations which are only updated once in eight days. When sargassum landings are predicted, then the coastal managers are able to prepare themselves. The number of people and equipment can be arranged beforehand, consequently financial costs are saved.

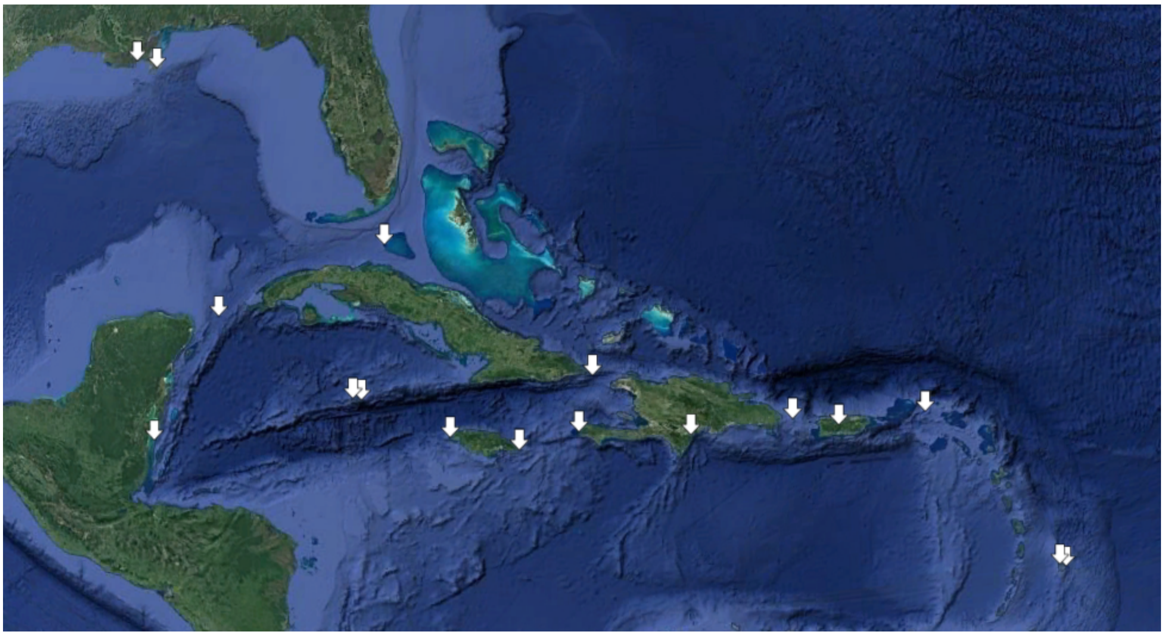

Figure 2.2: SEAS forecasting locations

2.3 University of Florida

The University of Florida operates the Satellite-based Sargassum Watch System (SaWS). This system provides links to satellite data for several areas in near real-time. These areas include the Eastern Caribbean, Central Atlantic, Western Gulf of Mexico, Eastern Gulf of Mexico and Bermuda [10]. SaWS observations are given for any time of any day. Every day, there are a few satellite images produced, including: an AFAI (Alternative Floating Algae Index) image to detect floating materials (sargassum) and current vectors, and a CI (Colour Image) image that helps to validate the HYCOM currents. Other types of images are provided as well, but that does depend on which area is used. Each satellite image can be applied on Google Earth. Using the AFAI and CI images one can see where floating materials are found and which ocean currents are driven them [19]. The SaWS system does not give any forecasts, because they do not have the capacity to perform forecasts. Some people already made use of the SaWS system to make short term land fall predictions (days to weeks).

2.4 University of Southern Mississippi

The University of Southern Mississippis Gulf Coast Research Laboratory maintains a reporting website that serves as a data collection center to accommodate reports of large quantities of sargassum observed within the region during 2015 [22]. With this a better understanding of the golden tides is created (see paragraph 1.3.1). The university does not give warnings of sargassum landings to coastal managers.

Chapter 3

Current harvesting methods

In this chapter, the current methods used for harvesting sargassum will be explained. The most common used harvesting methods are practised on the beach. This will be described in section 3.1. Because of the golden tides of the recent years, new methods for harvesting are in development as well. At this moment, a lot of research is done to methods where saragassum can be removed before it reaches the shore (see section 3.2).

In Mexico, the government has invested USD $9.1 million to clean up the sargassum along the Yucatan coastline on the shores in Cancún and the Riviera Maya [18]. Hotel- and resort owners located at the coast tried to clean up their own beaches to keep their guests satisfied. This was often without result because of the large amounts of sargassum approaching the beach. Several cleaning methods were applied.

In case of relative small quantities, sargassum is not defined as a problem, it even has an ecological value. Nevertheless, some hotel- and resort owners still clean their beaches to keep them most attractive for tourism.

3.1 Harvesting at the beach

With the golden tides surprising most affected countries due to a lack of detection, sargassum already washed ashore before any action could be taken. This resulted in beach cleaning methods.

Depending on the quantity, availability of manpower and equipment, access to the beach and the presence of wildlife like turtles and seabirds, a choice has to be made between manual and mechanical cleaning.

3.1.1 Manual

Manual removal is mostly done by hand raking and thereafter transporting with wheel barrows, bags or dragged by tarpaulins. It is often applied to protected or small beaches with relative low volumes of sargassum. Manual cleaning is very flexible and can take place in a great variety of locations.

Prerequisite is the availability of enough manpower. It requires a lot of labour and is time consuming. Besides cleanings by hotels and resorts there are a lot of cases where communities are getting involved. This way beach cleaning is also having a social aspect.

On the beach, manual cleaning is preferred over cleaning by machines, because off its low disruptive level, low likelihood of disturbing sea turtle nests and the smaller contribution to beach erosion [1] [9].

Figure 3.1: Manual harvesting

Table 3.1: Advantages and disadvantages of manual beach cleaning

Advantages	Disadvantages
Flexible	Lot of labour
Can take place in a great variety of locations	Time consuming
Relatively low beach disruption for beach tourism as well as local wildlife	Only able to clean up small volumes
	(relative low) Beach erosion

3.1.2 Mechanical

Where manual cleaning is not practical (in case of large sargassum volumes), mechanical equipment can be an option. But note that there are specific places where heavy equipment is not allowed to enter the beach[1]. There are various mechanical cleaning methods and machines, those will be explained below.

Mechanical beach rake

A mechanical beach rake is a tractor-towed beach cleaning machine and is effective on moderate quantities. It is the most common beach cleaning machine around the world. A rotating perforated conveyor belt containing tines rakes the beach gathering the sargassum and letting residual sand fall through. The sargassum is dumped into the hopper, which can be hydraulically raised and tripped to dispose its contents into a truck or container. For very large accumulations assistance of other equipment is necessary, since the beach rake can only clean beaches where the sargassum is not piled up too high [16].

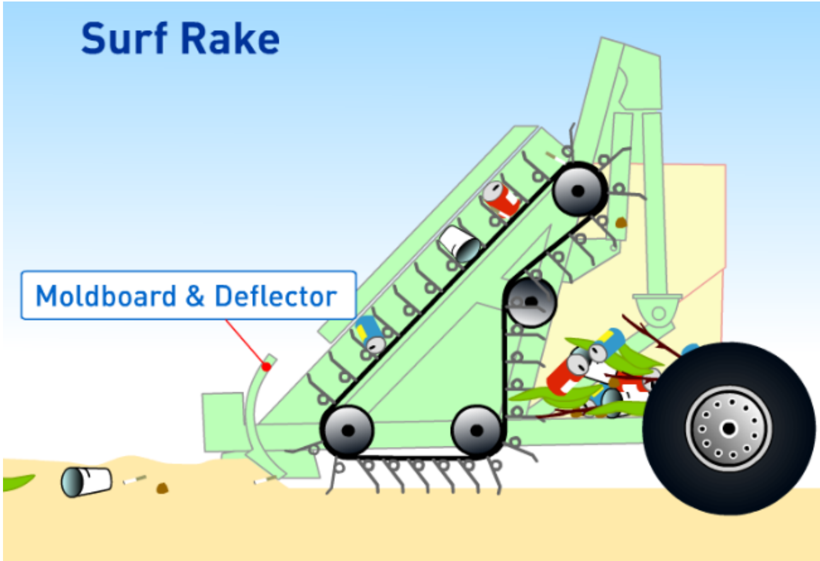

Figure 3.2: Mechanical beach rake [16]

Mechanical sifting sand cleaner

Sand sifting machines can only be used on dry sand and is available as a tractor-towed machine, a vehicle or a walk behind machine. The sand and sargassum are collected via a pick-up blade onto a vibrating screening belt, which leaves the sand behind. Subsequently the sargassum will be gathered in a collecting tray. The cleaning time will be long compared to the mechanical beach rake, because it takes the sand some time to sift through the screen. The sifter is highly manoeuvrable and only used for cleaning small volumes, which makes it unpractical during a golden tide [15].

Figure 3.3: Example of a small sifting sand cleaner [15]

Front-end loader

For sargassum piled up to a few meters, the two methods mentioned above are insufficient. In cases like this, heavy equipment is necessary for cleaning the beach. In some countries front-end loaders are used to remove the huge quantities. A front-end loader is most effective removing the top layer without touching the sand and building up big accumulations or dumping its load into trucks. Afterwards a mechanical beach rake, a sifting sand cleaner or manual removal can be used to collects the left behinds. As alternative to a front-end loader, a bulldozers with tracks and buckets can be used.

Figure 3.4: Front-end loader removes embedded sand [25]

Cane loaders

Another type of heavy equipment which has been used in different countries is a cane loader. A cane loader can pick up large quantities of sargassum of the beach. Just like with the front-end loader a mechanical beach rake, a sifting sand cleaner or manual removal has to be used to collects the left behinds.

Figure 3.5: Heavy equipment cleans embedded sargassum [6]

It is important to understand the risk of using heavy equipment. Experience has shown that heavy equipment is taking a lot of sand with it while cleaning the beaches, causing significant erosion. Especially a front-end loader, a crane and a bulldozer that spade the beach are removing large quantities of sand with the sargassum.[1]

This sand removal together with these heavy equipment driving on the beach endangers sand-dwelling critters, including possible sea turtles and nests. For this reason machines with large soft tires are preferred over tracked vehicles. The access to the beach of the heavy has to be kept to a minimum and all equipment should be following the same path to the shoreline [9].

Table 3.2: Advantages and disadvantages of mechanical beach cleaning

Advantages	Disadvantages
Able to clean up large volumes	Causes beach erosion
Able to clean long stretches	Endangers local wildlife
Relative short cleaning time	Not everywhere allowed
Relative low labour	Relative wide beach access necessary
	Expensive equipment
	Not environmentally sustainable
	Compacting beach sand, which affects turtle nesting

3.2 Harvesting at sea

Although sargassum removal on the beach is the most popular (and simplest) cleaning method a lot of negative impacts can be prevented when sargassum is harvested before it washes ashore. Therefore, several researches have been done to harvesting methods at sea.

A straight-forward method to remove sargassum from the sea is by use of boats in the shore face that have a harvesting function. Another removing method is a skimmer. A skimmer is a machine which is as normally used for oil removing during an oil spill operation. In addition to these removal methods, barriers can be used. A barrier is as a collecting method and contains sargassum against or near the barrier, this makes the harvesting operation much more efficient. At this moment, there are several barriers in development.

Most of these harvesting concepts have been designed recently and are therefore still under development. In section 6.1 these concepts will be further treated.

Chapter 4

Current processing methods

As sargassum is an organic material with a large extend, there must be some opportunities for sargassum as a useful source. The challenge in sargassum valorisation is that sargasum has a unpredictable appearing character. As previously mentioned in section 1.3, 2014 and 2015 were years with tremendous amounts of sargassum, in contrast to 2016 where the sargassum is not present in such quantities. The table below shows the chemical contents of sargassum. This will help to determine what processing possibilities are possible:

Table 4.1: Proximate analysis of mixture of *S. Natans* and *S. Fluitans* powder.

Content	Percentage (%)
Carbohydrates (by difference)	57.3±0.21
Protein	15.4±0.0
Moisture content	9.0±0.14
Ash	8.65±0.07
Crude Fibre	7.15±0.21
Ether extract (Fat)	2.5±0.07

As the amount of sargassum is only an issue since a couple of years, the use of the sargassum has not been optimised yet. In the following sections, the processing methods that are currently used will be described.

4.1 Burying sargassum at the beach

When sargassum is not just dumped, the most common way at this moment is to bury it under the sands. The positive side of this method is that the sand, collected with sargassum, is kept on the beach and will therefore not erode.

For wide beaches that experience low volumes of sargassum, especially those with dunes, burying the seaweed further up the beach or in the dunes may be a good option. Sargassum is an excellent medium for beach nourishment; it helps to counteract beach erosion and increases coastal resiliency to storm surges and rising sea levels.

However, on narrow beaches this practice is less suitable because there is insufficient space for burial. On top of that, it can also have negative impacts on turtle nesting beaches since the buried sargassum can change the organic composition of the sand and may decrease hatching success.

There is another big downside on this method. By burying the sargassum, its nutrients will get in the groundwater which eventually will flow back to the sea. These nutrients accelerate the grow of sargassum near shore.

4.2 Fertiliser

Sargassum is commonly used as a fertiliser as well. Seaweed used to fertilise the nearby soilis is an old practice already. The key in this process is to rinse salt using fresh water or use salt resistant crops. Some hotels are showing green initiatives by composting their own seaweed and use it in the garden. There are also local residents of coastal villages that have built small businesses by selling composted sargassum [7].

In different tests, brown algal mass has been composted, rinsed and then used in trials for growing tomato plants on various types of soil. In all cases, the addition of the compost increased the water holding capacity and plant growth, so composting simultaneously eliminated the need for chemical growth stimulants and captures CO_2 in the accelerated plant growth.

The composition of sargassum shows similarities with common chemical fertilisers but the exact concentration is different. Nitrogen and potassium concentrations are appropriate, but the phosphorus concentration is lower than in traditional animal manures and the typical N:P:K ratios in chemical fertilisers. Phosphorus is linked to a plants ability to use and store energy, including the process of photosynthesis.

The large amounts of insoluble carbohydrates in sargassum improves aeration and soil structures, especially in clay soils, and has good moisture retention properties. Their effectiveness as a fertiliser is also sometimes attributed to the trace elements they contain, but the actual contribution they make is very small compared to normal plant requirements.

Seaweed extracts and suspensions have achieved a broader use and market than the use of seaweed in its original form. They are sold in concentrated form which makes them easier to transport, apply and act more rapidly. One of the earliest patents was applied for by Plant Productivity Ltd., a British company, in 1949. Today there are several products and brands available.

4.3 Biofuel/biogas

Recently, the attention for using marine macroalgae for the production of biofuels is increased. Terrestrial crops offer excellent biogas recovery, but will also compete directly with food production, occupying farmland, fresh water and fertilisers. Using marine macroalgae for the production of biofuels does not require these needs.

The conversion efficiency of watery organic matter to biogas is one of the highest of any biofuels [3]. The ability of seaweeds to absorb CO_2, their rich carbohydrate content and lack of lignocelluloses increase their potential use for biogas production. Because sargassum biofuel conversion is not done yet, this topic will be discussed further in chapter 7.

4.4 Food

As seen in table 4.1, sargassum contains a high amount of proteins, therefore it could be a possibility to use sargassum as human or livestock food.

As mentioned in the section above, the lack of competition with terrestrial crops is a positive part. But sargassum can also contain inorganic elements from seawater like heavy metals or other mineral contaminants. Using sargassum as food can thus be a risk and is therefore subject to national and international regulations concerning their content in trace elements. In the European Union, calcareous marine algae must contain less than 10 mg/kg of arsenic, 15 mg/kg of lead and 1000 mg/kg of fluorine; seaweed meals and seaweed-based feed materials must contain less than 40 mg/kg of arsenic, and less than 2 mg/kg if requested by the competent authorities (all values relative to a feed with moisture content of 12%) (Commission Regulation N574/2011 amending Annex I to Directive 2002/32/EC, 2011). As there has not been any large scale implementation, the details will be discussed in the opportunities part, chapter 7 [23].

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Part B

In 'Part B', the current detection methods are evaluated. The methods are criticised on different criteria in a multi criteria analysis (MCA). This is done in order to find the best working method. The aim is to develop countries without a detection system. With this analysis the important aspects can be noted in order to develop an improved system.

As the detection methods, the harvesting methods are evaluated. Additionally, new ideas to harvest are thought of and explained. All of the harvesting methods are criticised in a multi criteria analysis as well. The recommended methods are further elaborated.

At the moment sargassum is mostly seen as a plague, although the contents of it offers opportunities to use it as a valuable source for the production of many products.

Chapter 5

Detection improvement

In chapter 2 the current detection methods have been explained. It became clear that many countries do not have a proper detection system and that the only institutions that have developed a system are three universities, mainly focused on the coasts of Texas and Florida (USA). In section 5.1 of this chapter the current detection methods will be evaluated and validated with a multi criteria analysis in section 5.2. The intention of this chapter is not to develop a new detection method, but to discuss whether some aspects of existing methods can be used to improve a strategic approach for countries without a detection system.

5.1 Evaluation current methods

5.1.1 Reactive systems

In section 2.1 a reactive system is outlined. More nuisances are present in countries that use reactive systems than in countries that use a proactive system. Many costs can be saved when sargassum landfalls are known, because equipment and man power can be estimated beforehand. It can be concluded that the detection system of countries without a detection system will be more effective when it is a proactive system instead of reactive system.

5.1.2 Texas A&M University Galveston

As mentioned in section 2.2, the system along the coast of Texas is proactive due to the landfall predictions by SEAS. This system is therefore more efficient compared to the most other countries in the Caribbean Sea. The landfall predictions from SEAS can help to improve the coastal problems in other countries significantly. The communication between interested stakeholders along the coast and SEAS ensures better predictions, resulting in lower costs and nuisances. In many other countries communication is an aspect that has to be improved.

5.1.3 University of Florida

The University of Florida controls the SaWS system (see section 2.3). Due to the real time movements of sargassum, the predictions are more accurate. Considering this accuracy, the SaWS system has potential opportunities to improve the detection systems in many other countries. It will be a large benefit, if there is an agency or company which could validate the data of SaWS and is able to make landfall predictions for those countries.

5.1.4 University of Southern Mississippi

The University of Southern Mississippi has a large database that provides information about previous sargassum landings. The database can be used as a rough estimation for coming golden tides and helps to determine which locations will probably suffer the most from the incoming sargassum. The university mainly has data for coasts of the USA (especially for Florida), therefore this data cannot be used to make predictions for other countries.

5.2 Multi criteria analysis

The four given methods will be evaluated with a multi criteria analysis. This consists of ranked multiple criteria, see paragraph 5.2.1. The given methods are validated on these criteria in paragraph 5.2.2. Finally, based on the outcome of the multi criteria analysisa, a conclusion will be drawn.

Table 5.1: Detection methods

1	Reactive systems
2	Texas A&M University Galveston
3	University of Florida
4	University of Southern Mississippi

5.2.1 Ranking of the criteria

The explanation of the criteria and the ranking of the criteria can be found in appendix B.1. The higher the weight factor the more important the criterion is. The results of the ranking are shown in table 5.2.

Table 5.2: Detection criteria ranked

Criteria	Weight factor
Forecasting time of landfall predictions	1
Applicability	0.81
Accuracy	0.60
CAPEX	0.24
OPEX	0.24
Output	0.16
Update frequency	0.11
Feedback	0.06

5.2.2 Validation of the methods

The methods are validated on the criteria and their final score is shown in the table 5.3. For the argumentation of this validation consult appendix B.1.

Table 5.3: Validation of the detection methods

Methods	End-value
Reactive systems	9.98
Texas A&M University of Galveston	**23.69**
University of Florida	22.4
University of Southern Mississippi	10.4

5.2.3 Conclusion

According to the MCA, the detection system of the Texas A&M University Galveston has the highest score, therefore it can be concluded that this is currently the best detection system. This is mainly due to the accuracy of the system and the forecasting time. The CAPEX and OPEX are rather high compared to the other systems. The detection system of Florida is runner-up. It scores slightly lower because it lacks landfall forecasts. The working of these two systems can be of great help in the improvement of detection systems in other countries. In order to test the effectiveness of detection systems in other countries more research has to be done.

5.3 Detection system improvement

As mentioned previously, the scope of this chapter is not to come up with a new detection method, the technical methods of today are sufficient enough. The methods of SEAS and SaWS have proven to work properly. Asociación de hoteles de Cancún y Puerto Morelos have signed an agreement with University of Texas (SEAS) [14]. This indicates the applicability of the system to other countries. Nevertheless, in countries without a detection or forecasting system the strategic approach can be improved significantly. Due to the evaluation and the multi criteria analysis, it became clear which aspects are important for a detection and forecasting system. Another important aspect is communication, since there are many stakeholders involved. For implementing a system in a country without a detection system, these aspects have to be kept in mind. Several studies shall can be conducted in order to get to a better strategical approach. These studies include a history research, a project site research, a stakeholder study, a forecast study, a market study and a webcam study. When the detection system works properly in a new country, the focus should be to enlarge its scope. In section 8.2 these studies are further explained in an implementation plan.

Chapter 6

Harvesting recommendation

In chapter 3 the current treatment regarding harvesting at the beach and several concepts of harvesting at sea were mentioned. In section 6.1 the concepts for harvesting at sea will be further treated. With these studies to current and conceptual cleaning methods a lot of knowledge is gained which gave the inspiration for two more harvesting methods, which will be elaborated in section 6.2. In section 6.3 the harvesting methods will be analysed with a multi criteria analysis in order to determine which method has the largest potential.

6.1 Harvesting at sea

As explained before, the following concepts for harvesting at sea are still under development. In appendix B.2 more details about those concepts can be found.

6.1.1 Harvesting boats at the shoreface

A straight-forward method to remove sargassum from the sea is by use of a boat at the shore face. A large benefit is that boats are flexible in their movement and that they can transport the harvested sargassum to land. Harvesting boats can be simple barges- or catamarans with a harvest function. Two examples of boats used for the harvesting of sargassum are the water plant removal boat and the catamaran with a shovel. Details about these methods can be found in respectively appendix B.2.1 and B.2.2.

Figure 6.1: Water plant removal boat

Figure 6.2: Catamaran with a shovel removing sargassum

Table 6.1: Advantages and disadvantages of harvesting boats

Advantages	Disadvantages
Flexible (movable)	Fuel consumption (not sustainable)
Harvesting and transport combined	No deep draft possible

6.1.2 Skimmer

Apart from boats, a skimmer can be used as a remover method. A skimmer is a machine that removes oil during an oil spill operation. The working is shown in figure 6.3. The oil can be transported to land or to a boat by use of a long hose. Instead of oil, sargassum has to be transported. Another point to mention is the content of sand in the water, which can destroy an oil spill pump. Together with several other technical aspects it is therefore necesarry to adjust the oil skimmer pump for the removal of sargassum. More specifics of a concept of a saragassum skimmer can be found in appendix B.2.3.

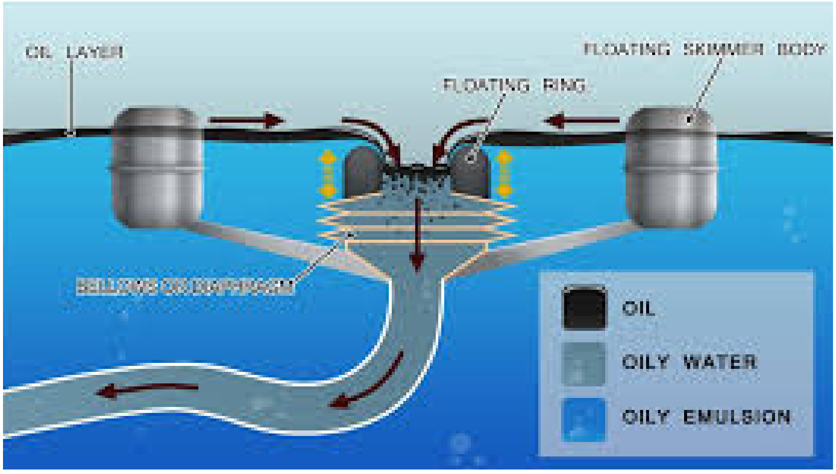

Figure 6.3: The working of an oil skimmer [5]

Table 6.2: Advantages and disadvantages of skimmer

Advantages	Disadvantages
Design based on proven technology	Collecting and transporting method required
Can be positioned in any area of interest	Needs adjustment for sand flow

6.1.3 Additional collecting methods

To make the harvesting operation for a boat or skimmer more efficient, a collecting method such as a barrier can be used. A barrier contains sargassum against or near the barrier thereby preventing it to wash ashore. This is not a new technology as they are for example often used in oil spill operations and could play a key role in the removal of plastic debris in the ocean (The Ocean Cleanup [13]).

There are two designs of barriers: a containing barrier and a reflecting barrier. A containing barrier is a system that physically stops the movement of sargassum and contains it against the barrier. A reflecting barrier will not contain the sargassum directly, but will reflect the incoming waves thereby keeping the sargassum at distance. The intention of using a reflective barrier is to decrease the chance of accumulation against the barrier. The barriers are described in more detail in appendix B.2.4.

Figure 6.4: Containing barrier

For both barriers a quick harvesting method is necessary. A mat of sargassum could block the sun which could lead to reduced photosynthesis. Also, when large amounts of sargassum are piled up against the barrier, the sargassum could be able to float under the barrier. If the sargassum is not harvested in a certain time, it will decay and eventually sink to the bottom [12].

Table 6.3: Advantages and disadvantages of barriers

Advantages	Disadvantages
Sargassum is collected at one place	Large accumulations can cause several problems as sinking material and the ability to pass the barrier
Design can be made removable	Quick harvesting necessary
Design based on proven technology	Accumulations can block the sun, causing ecological degradation
Effective in keeping the beaches clean	Must be resistant to rough weather conditions
	Not flexible in movement

6.2 Suggestions

Besides the current and conceptual harvesting methods, two new methods arose during this research.

The first method includes the use of an offshore harvesting boat. More details of this method can be found in appendix B.3.1. It seems logic to solve the problem close to its source which in this case will be offshore, but as explained in paragraph 1.1.2 sargassum houses a lot of different species and has an important role in the ecosystem. Hence, offshore harvesting will have a significant impact on the environment and encounter a lot of resistance of environmental groups. Therefore this method is undesired and will not be further treated in this research.

In the second method, the floating sargassum will be blocked by means of lines of beach poles perpendicular to the coast. For this method a more detailed explanation can be found in appendix B.3.2. Because further study has to be done, this method will disregarded in this research.

6.3 Multi criteria analysis

Now there are five possible harvesting methods excluding the new suggested methods (table: 6.4). These methods will be evaluated with a multi criteria analysis in the same manner as the detection methods in section 5.2. At the end of this section a recommendation for a harvesting method will be given.

Table 6.4: Harvesting methods

1	Hand raking on the beach
2	Mechanical equipment on the beach
3	Harvesting boat at the shoreface
4	Harvesting boat with a barrier
5	Skimmer with a barrier

6.3.1 Ranking of the criteria

Table 6.5 shows the criteria that are used to evaluate the methods. The higher the weight factor, the more important the criterion is. The description of each criterion and their ranking can be found in appendix B.4.1.

Table 6.5: Harvesting methods

Criteria	Weight factor
Ecological impact	1
Beach erosion	0.85
Removal Capacity	0.85
Applicability	0.56
Operability	0.56
Movability	0.41
Cleaning time	0.41
Removing efficiency	0.39
CAPEX	0.24
OPEX	0.24
Quality harvested sargassum	0.16
Labour intensity	0.10
Impact on Tourism	0.06

6.3.2 Validation of the methods

Now all criteria and their importance is know, the harvesting methods can be validated on the criteria. Table 6.6 shows the final results. For the argumentation of this validation consult appendix B.4.3.

Table 6.6: MCA: Final results harvesting methods

Harvesting methods	Final score
Hand raking on the beach	33.74
Mechanical equipment on the beach	34.62
Harvesting boat at the shoreface	**42.66**
Harvesting boat with a barrier	**45.55**
Skimmer with a barrier	38.07

6.4 Conclusion

From the multi criteria analysis can be concluded that a harvesting boat with a barrier has the highest potential. This will therefore be the recommended method. High potential lies within barges with an extra system for harvesting. The characteristics of the equipment and the exact processing method depends per case. In section 8.3 an elaboration is given for a specific golden tide project.

When a barrier cannot be applied, harvesting boats at the shore face will give the best results according to the MCA. But one has to keep in mind that this method especially scores good on environmental related aspects and that the exact efficiency still has to be researched. In theory a skimmer with a barrier will also lead to good results, but equal to the other methods: workability and efficiency have to be researched in a later stage of development. Beach harvesting methods result in rather low scores and will therefore only be favoured as an additional back-up plan or when none of the other methods for some reason can be applied.

Chapter 7

Processing opportunities

Chapter 4 states that there are only a few other processing methods being performed besides dumping or burying at the beach. One of the main reasons is the variable presence in which sargassum appears. To make sargassum a useful and profitable source, one has to overcome the discontinuity of the droppings.

Fertiliser supplement remains a good option because the time needed for composting is indefinite. When looking at other opportunities, drying could provide a solution for the uneven appearances. When sargassum is dried and milled the volume decreases drastically because of the large presence of water in the harvested sargassum. This way the sargassum will not decompose and is easier to store sargassum for longer periods. In this chapter some other opportunities for alternative processing methods are described.

7.1 Food

Using fresh sargassum as source for food is not a good solution, because sargassum only comes in very large quantities during golden tides. Though the large protein content of sargassum makes it a possible food supplement, it is simply too much to consume the estimated one million tonne (section 1.3) that washes ashore in a few weeks.

7.2 Bioplastics

Plastic pollution is a worldwide problem. Bioplastics are a sustainable alternative to traditional plastics. They are plastics that can be made from various biomass resources and are faster degradable than traditional plastics which are typically made from petroleum or other fossil resources. By using bioplastics instead of the traditional plastics, CO_2 emission from fossil fuel will be reduced and fossil resource will be preserved.

Common used resources have certain limitations such as non-availability of high biomass and difficulties involved in cultivation. Seaweeds can serve as one of the alternatives because of its high biomass and its natural polysaccharides that can be extracted from them. Those polysaccharides can be used to create biodegradable and high quality bioplastic [4]. The European union is investing in this method and currently several companies have succeeded in making bioplastics out of cultivated seaweeds [2] as well. Producing plastic from sargassum is more difficult, but can provide a large cost saving compared to cultivated seaweeds.

There are some challenges in making bioplastics out of sargassum. At first the composition is not uniform and it can be contaminated. On top of that, the process of harvesting could influence the quality of sargassum. To ensure a high quality, the sargassum has to be collected at sea. Subsequently it will be transported to shore where it will be dried quickly and baled to maintain its quality and freshness. Afterwards it will be mechanically grounded, sieved and extensively washed. A good harvesting method at sea is prerequisite.

7.3 Biofuel

Due to the growth of the world population and their energy demand, the fossil fuels are running short and the emission of $C0_2$ increases. This increases the attention for search to renewable energy sources .

There are multiple generations of biofuels. The first generation biofuels are made of terrestrial crops leading to direct competition for food production. The second generation are the fuels produced from terrestrial waste and residual biomaterials. They do not compete with food resources, since the base for production consists of undesired waste biomaterials. It can be considered as a generation process of bioenergy with the simultaneous treatment of biowastes. The process quality and conversion efficiency are hard to control due to the resistance of the woody and lignocellulosic biomaterials to microbial conversion. Seaweed biomass does not have lignocellulosic material like that and is therefore easier to transform to an energy source. Cultivated aquatic biomass fuel is called the third generation. The ability of seaweeds to absorb CO_2, their rich carbohydrate content and lack of lignocelluloses increase their potential use for biogas production. Where third generation fuels are made from alginates that are cultivated for their use as an energy source, sargassum biofuel would be a fourth generation biofuel. Fourth generation biofuel is made from non-cultivated seaweeds.

There are a few suitable conversion technologies for the sargassum energy conversion. These technologies are explained in the next paragraphs.

Table 7.1: Conversion technologies for biofuel [9]

Method	Utilises entire organic biomass	Requires biomass drying after harvesting	Primary energy product
Thermal combustion	Yes	Yes	Heat
Thermal Gasification	Yes	Yes	Primarily Gas
Pyrolysis	Yes	Yes	Primarily liquid by fast pyrolysis
Bioethanol	No	No	Liquid
Anaerobic digestion	Yes	No	Gas

7.3.1 Thermal combustion

The easiest way to convert sargassum to energy is by thermal combustion, where sargassum is simply burned to provide thermal energy. Another form of thermal comvustion are biobriquettes.

Dry macroalgae are easy to ignite, but have a low thermal value typical of carbohydrate-rich biomass (1416 MJkg^{-1}) [9]. By carbonizing and compressing the seaweed, ready-to-use and easy to transport briquettes are obtained, which can replace wood carbon briquettes.

7.3.2 Thermal gasification

Thermal gasification is a way to convert sargassum biomass into H_2 gas. Gasification is the process where a biomass source is heated to a high temperature ($\geq$ 700 °C) without combustion and with a controlled amount of oxygen and steam. The output of the process consists of carbon monoxide, hydrogen and carbon dioxide. The output gas is called 'syngas' which can be used to power turbines or it can be converted in other kinds of fuels using the Fischer-Tropsch [1] process.

7.3.3 Pyrolysis

The process of pyrolysis is basically the heating of an organic source in the absence of air. Fast heating pyrolysis can produce a bio-oil end product. The conversion yield can be around 75%, compared to between 15% and 65% achieved through slow pyrolysis [15]. Bio-oil is considered to be a more favourable end product than syngas, as it has a higher energy density and is easily transported and stored. The challenge in bio-oil production is the needed high heating rate of 200 Cs^{-1} [10]. Further research is needed to apply this method with sargassum.

7.3.4 Bioethanol

Bioethanol can be produced by the action of microorganisms and enzymes through the fermentation of various hydrocarbon chains. One of the challenges in ethanol production from terrestrial crops is that the conversion of hemicelluloses and cellulose is a difficult process. Sargassum does not contain significant quantities of those materials which makes it a better source for ethanol conversion. A drawback is that sargassum contains low amounts of polysaccharides composed of glucose. Ethanol needs to be produced from other carbohydrate components of sargassum, including sulphated polysaccharides, mannitol, alginate, agar and carrageenan [16]. However, some of the sugars produced from the breakdown of seaweed polysaccharides such as xylose and rhamnose are poorly utilised by yeast, such Saccharomyces cerevisiae. The lack of tractable microorganisms that can efficiently convert the monosaccharides derived from seaweed into ethanol is considered one of the major limitations of macroalgae as a bioethanol feedstock.

7.3.5 Anaerobic digestion

Anaerobic digestion, also called biologic gasification, is the breakdown of organic matter by microorganisms in the absence of oxygen. The products of this process are CO_2 and CH_4 (methane). Tokyo Gas demonstrated that 20 m^3 of methane can be produced from one tonne of seaweed and to power a 9.8 kW electrical generation plant [11]. Because of the lack of lignocelluloses cells the rest product will be less than in case of using terrestrial crops.

7.4 Alginate

The alginate content in sargassum seems promising for a process opportunity. It is around 45% percent of the dry-weight [8].

Alginate is a hydrophyle polymer consisting mainly of algine acid, a polysaccharide built from mannuron and guluron acids. It is usually sold as a powder which hardens a flexible rubber like substance after drying.

Alginate extracts are for example used in textile dye, health, cosmetics or as wound dressing. In the food industry alginates are used to stabilise mixtures, dispersions and emulsions, which increases viscosity and forms gel, such as jams and jellies. Dentists are using alginates to make dental imprints because of its non-toxic and fast drying properties, some disadvantage of alginate are the inaccurate and deforming characteristics when drying [3].

7.5 Building insulation material

The lack of fibres in sargassum reduces the possibilities to use it as a structural component. There are examples about the use of seaweed as a non-structural building material.

In Denmark, seaweed is a known insulation material for over a hundred years. Recently Danish architects reinvented this use of seaweed. Sargassum has a good insulation potential with its air bladders [6].

Figure 7.1: Seaweed as building insulation

7.6 Binding material

Another application of a seaweed growing in Denmark, which is very similar to sargassum, is making use of the binding properties of the seaweed. The binding properties are provided by the alginate mentioned earlier.

Designers Jonas Edvard and Nikolaj Steenfatt are combining cooked seaweed powder with waste paper to create a tough and durable material similar to cork. Seaweed is providing the binding and paper wasted contains the needed fibres [7].

Similar processing options are possible with sargassum and other fibres then paper. Corn is a very common used product in the Mexican cuisine, the leafs and stem of a corn plant contain very strong fibres. A corn fibre with sargassum variation on the Danish concept could be possible use.

7.7 Conclusion

Drying the sargassum creates a useful raw material with different applications. The lack of fibres in sargassum channels down the possibilities. Bioplastic is an use which can replace plastics made out of fossil fuel, but creating a high quality bioplastic is a difficult process. As a large biomass source, sargassum has a potential to make fuel out of. It reduces the use of fossil energy sources and releases no extra CO_2 in the atmosphere then captured during its growth.

The world-wide demand for alginate is too small to provide a use for the alginate from all the sargassum. Alginate has binding properties that can be used for new applications as a non-chemical binding agent. Further research is needed to create a feasible method to convert sargassum in energy of other useful material.

Table 7.2: Conclusions processing opportunities

Processing	Pros	Cons
Food	Protein production without cultivation	Fresh sargasssum no solution for quantities golden tides
Bioplastic	Environmental friendly	Production process in development replacement of current plastics
Biofuel	No fossil CO_2 release	Production process in development
Alginate	Replaces cultivated seaweed	Replaces cultivated seaweedSmall demand
Building insulation	Replace produces glass-wool	Only small scale practise
Binding material	Not water resistant	Recyclable after lifetime

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Part C

With the knowledge gathered in 'Part A' and 'Part B', a solution for a next golden tide can be provided. A project of such size cannot be implemented straight away. The missing link in the approach for a comprising solution is especially a party who will take the lead and direct the project. Research has to be done, large investments has to be made, complete products have to be developed and stakeholders need to be involved. This part describes a strategic approach that will help a company to do so.

'Part C' provides a step-by-step approach to come to a final solution. The first phase of the implementation plan is the least complicated phase and can be started directly. Phase 2 will contain an advice for the implementation of the solution at a chosen pilot location. Phase 3 is the final stage where a working detection, harvesting and processing method is provided for the touristic parts of the complete coast of Quintana Roo. Important factors that have to be taken into account are the coral reefs, seagrass areas and the protected marine areas in front of the Quintana Roo coast. In appendix C.1 a map that points out those specific places can be found.

Each phase is divided similarly as the previous parts: detection, harvesting and processing. In the end of this chapter a roadmap is provided to depict a graphical overview of the steps that have to be taken.

Chapter 8

Implementation

8.1 Introduction

For the protection of the complete coast of Quintana Roo a large investment is needed and a lot of stakeholders need to be engaged. For this reason, phase 1 provides a pilot location. The chosen pilot location is a 12 kilometres long beach stretch at the east coast of the Zona Hotelera (Punta Nizuc - Cancún), shown in Figure 8.1. Protection systems for other parts of the coastline will be largely similar and can be implemented in later phases.

Figure 8.1: Pilot case coastline

This coastline is selected for several reasons. Cancún together with Playa del Carmen are forming the locations with the highest touristic rate along the coast of Quintana Roo. The beaches along Punta Nizuc - Cancún are all in front of hotels and resorts. These resorts cooperate through the 'Asociación de hoteles de Cancún y Puerto Morelos'. Especially cooperation and funding will be easier in collaboration with this organisation. Besides tourism in Cancún took a hit by the golden tides in 2014 and 2015, harming the revenues of most hotels in this area. This increased the interest in a solution for prevention of recurrence.

For the design of the implementation plan some assumptions had to be made. Clear quality data about quantities is hard to obtain because the golden tides were a surprise each year. Making a single institution responsible for the collection and standardisation of the data about quantities is an important recommendation. As stated in section 1.3, the available quantity data at this moment came from the 'Secrets Resort'. The highest recorded influxes were around 200 kilograms per linear metre beach, some outliers aside. These numbers describe the harvested sargassum at the beach, and thus includes sargassum contaminated with sand. The sand amount is estimated to be 20%. The proposed solution must be able to handle this quantity.

The selected 12 km of coast together with the numbers per metre gives us an estimation of the total quantities that can be expected for phase 1. Sargassum on the coast will appear in loose large mats on the coast as stated in parapraph 1.2.4. The size of these mats will not be sufficient to give a maximum sargassum influx on the total stretch of 12 km. A factor 0,7 is used in order to take this effect into account.

The total estimated sargassum washing ashore along the 12 km pilot location will be:

$$200 * 12000 * 0,7 * 0,8 = 1344 \qquad \text{tonnes per day} \tag{8.1}$$

8.2 Detection improvement

Quintana Roo does not have a fitting detection system because only once per 8 days a very brief forecast is given. Other detection of sargassum is currently done by fishers or people looking at places further upstream where sargassum landfall occurs, like Barbados. These detections are poorly communicated with all the interested stakeholders along the coast. Moreover, these forecasts are inaccurate and the forecast provided by fishermen is time limited. For the largest part of the coast even no forecasts are given at all. This makes the system of Quintana Roo rather reactive, instead of proactive.

In order to improve the forecasts and detection development for Quintana Roo, a strategic approach is requisite. In section 5.3 is explained that several studies should be conducted in order to help improving countries without a detection or forecasting system. In the following paragraphs the mentioned studies are consulted and elaborated for Quintana Roo.

8.2.1 Phase 1

In phase 1, time is too short to improve the whole detection system. Therefore, the 8-day SEAS forecast shall be used during this phase. The improvement should be started with a literature study and stakeholder involvement.

Literature study

As suggested in section 5.3, the following literature study researches are useful for the coast of Quintana Roo.

History research: Old local newspapers have to be analysed in order to get a sense of what impact the golden tides had on different locations. The old local newspapers have to come from at least five towns along the coast. Tulum, Akumal, Playa del Carmen, Puerto Morelos and Cancún are chosen for the given stretch, because they are the biggest towns along the stretch and located at approximately equal distances. For these towns the old newspapers should be studied over the last 50 years. By means of this study it will become clear on which day at which town sargassum landings occurred. Perhaps, also information about quantities can be found, which can be useful in developing harvesting methods. All the found information should be collected in a database. The SEAS system started their program this way as well for the coast of Texas. Besides it is important that not only previous sargassum landings have to be registered, but a database has to be kept up to date.

Project site research: The wind and wave conditions, near shore and offshore, have to be analysed for the chosen locations. The basis for the wind and wave patterns is already given in paragraph 1.2.1 and appendix C, but this study should be further researched for the given location in order to give the complete conditions. The bathymetry should be mapped along the given stretch, including indications of the coral reef locations. In appendix C.1, maps are provided for the given stretch and the existing coral reefs. An environmental study is suggested for harvesting methods, considering the presence of coral reefs. At these locations harvesting the sargassum has to be done with extra care, since the coral reefs are special ecosystems and they could easily be damaged.

Finally, links between the history- and project site research can be studied. Wind conditions, wave conditions and bathymetry are influencing the sargassum landings on the different locations. This could help to predict and prepare for future large sargassum beaching events and sets the base for a new strategic approach.

Stakeholder study

This study focuses on all the involved stakeholders. The first step is to identify all stakeholders that are involved with a potential detection system. A complete overview with all the involved stakeholders is needed. There are a lot of stakeholders involved with a detection and forecasting system. An overview should include the government, municipalities, port authorities, environmental organisations, hotels and restaurant owners, fisheries, harvesting- and processing companies. Step 2 is to analyse the stakeholders. Understand their interest and perspectives. Step 3 is the mapping of the stakeholders. Visualise relationships to objectives and other stakeholders. Finally step 4 is to prioritise the stakeholders by ranking their relevance and identifying their issues.

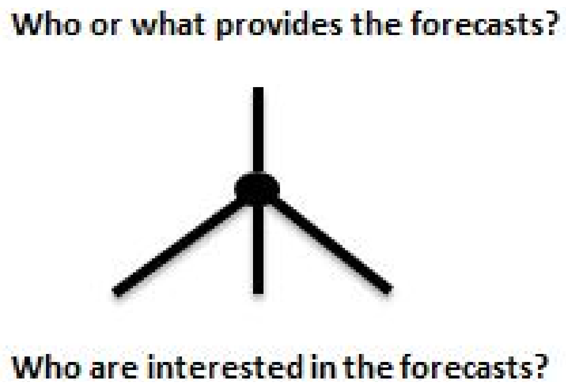


Figure 8.2: Sketch for the stakeholder study

Both question of figure 8.2 are further elucidated in the following studies: ”Forecast study” and ”Market study”.

Forecast study

The question ”Who or what provides the forecasts?” is researched in chapter 2. At this moment the best methods to detect sargassum is with the SEAS or SaWS system, they both use satellite images provided by NASA. According to the MCA in section 5.2, SEAS scores slightly better. This is mainly due to the forecasts of the sargassum landings, which SaWS is not providing. A forecast of sargassum landings will not radically differ within a scope of 5 kilometres. The aforementioned towns in the history research be well used as forecasting locations.

It is advised to contact SEAS for developing a detection method for the coast of Quintana Roo, because they provide forecasts and have experience in testing. Forecasts has to be financed, therefore a financial study and market study should be conducted. For the market study and financial consult the next paragraph.

In case the cooperation with SEAS will not succeed, opportunities with SaWS have to be studied. The disadvantage is that SaWS does not provide forecasts. The short-term predictions which are made by individuals using SaWS should be validated. These forecasts should be accurate enough and the forecasting time should be sufficient, because this is important for preparations. If these 2 points are met, the system can be used for Quintana Roo. Else, a predicting tool has to be programmed in order to convert the SaWS data to forecasts of sargassum landings on longer time scales. This will cost more money and time.

Market study

"Who wants the forecasting of sargassum landings?"

As explained above, there are many stakeholders along the coast who can benefit from the forecasts of sargassum landings. This also applies to Quintana Roo. 'Asociación de hoteles de Cancún y Puerto Morelos' has signed an agreement with University of Texas (SEAS) [8]. This indicates that hotels are willing to pay for the forecasts and that the SEAS system is applicable in other countries.

As was explained in section 2.1 there is no cooperation between the stakeholders at this moment, each stakeholder takes care of his own problem. In order to counteract the influx of sargassum with a good strategy, the communication between the stakeholders is very important. The forecasts will not be very different for hotels within a certain distance, this has to do with the wind and current patterns. Therefore, it is reasonless for hotels within this certain distance to pay parted for the same forecast. An umbrella organisation should get the forecasts for the 5 mentioned towns and forward them to the hotels and other interested stakeholders. This would save money and the umbrella organisation could help validating the forecasts for Quintana Roo.

In Mexico all of the beaches are owned by the government. Therefore, the government also takes responsibility in keeping the beaches free of sargassum inundations. The Mexican government should be willing to invest in solutions for the golden tides. The umbrella organisation should discuss the financial aspects of the detection and forecasting system of Quintana Roo with the government.

For the first stage in implementation the focus should be on Cancún. In Cancún the hotel owners, beach restaurants and other interested stakeholders along the beaches have to be contacted. Once the detection and forecasts are working for Cancún, the system can be enlarged to Playa del Carmen and Tulum. After Cancún these 2 towns are the bigger ones. The detection and forecasting system can be finalised by enlarging to Puerto Morelos and Akumal.

8.2.2 Phase 2

After completing all needed researches and involving the right parties in the Cancún area, the moment has come to judge the working of the system and where possible improve it.

Webcam study

The opportunities of a webcam platform can be discussed during the market study with the hotels or other interested stakeholders. Several hotels already have a webcam with a beach view [3]. The umbrella organisation could build a website where the stakeholders can monitor the other locations along the coast. It is important that the sargassum is clearly notable on the webcams. This has two important advantages. Firstly, it can be used as a short-term forecast. And secondly, it can function as feedback for the forecasting and detection method.

8.2.3 Phase 3

On the long term when a proper detection strategy is working, the scope can be enlarged by integrating the whole coast of Quintana Roo and the islands in front of it (i.e. Isla Mujeres and Cozumel). When the new approach is successful, more studies can be done on other parts of Mexico (like Yucatan) to find out where sargassum landings are taking place. It will be a big step to integrate this system in Mexico, in which many different social, political and financial problems have to be examined. In an ideal situation, Mexico and the states of America along the Gulf of Mexico are working together in one system. Where besides detection methods also the harvesting and processing methods are shared. On the long-term, a technical idea is to integrate image recognition to be able to detect sargassum through the webcams automatically.

8.3 Implementation harvesting

Harvesting may be the most difficult part of the solution for the golden tides. Implementing a plan is comprehensive and requires a large investment. This section will consider the implementation of the proposed method in chapter 6; A barrier with multiple harvesting ships. The phases as mentioned in 8.1 will be maintained.

8.3.1 Phase 1

The first phase for harvesting is very basic, the solution as provided in 'Part B' needs a custom designed barrier and a purpose built system to collect the sargassum in a barge. Even implementing parts of the proposed solution in 'Part B' is not feasible. Removing sargassum in the coming two year needs to be done by collecting it on the beach.

Phase 1 for harvesting will largely consist of gathering the right data, sort out the funding and start with the design of a barrier. Right now tests are conducted with a barrier-like structure by 'The Ocean Cleanup' to research how their floating barrier fares in extreme weather at sea and validate the survivability of the system [7]. This makes 'The Ocean Cleanup' a valuable possible partner in the design for the sargassum problem.

Another topic that has to be researched are the harvest boats which will probably need a larger investment than the barrier. For funding the two most imported stakeholders are the government and the hotels-owners. During past golden tides, the government invested a lot in the manual cleaning. For the implementation of a new solution, a much higher investment is needed. The government will not provide this investment all alone. Hotel-owners are the ones having the most benefit from the barriers. 'Asociación de Hoteles de Cancún y Puerto Morelos' is an organisation where most hotels in the area are represented. They can cooperate through this organisation to provide the needed funding.

8.3.2 Phase 2

Stage 2 is the moment where the development of a barrier is completed. The harvesting ships will not be finished at this point but the barrier can be installed along the 12 km stretch of coast in Cancún as mentioned earlier. Because time is too short to already have developed and built a harvesting ship solution, the collection of sargassum should be done in an improvised way with local available (fishing-)boats and for example nets.

Barrier installation

In front of the coast multiple anchoring point should be installed. In case the detection system forecasts a large influx of sargassum, the barriers can be put in positions as quick as possible. Because in front of the Zona Hotelera there is no coral reef (Appendix C.1), whether a barrier can be applied is especially dependent on the sea state conditions.

In appendix C.2 and C.3 the data for swell- and wind direction, wind force and wave height are given. The wave heights measured were 0-2 m . It is important that the waves do not break at the location of the barrier. The depth where a 2 m wave will break can be calculated with the rule of thumb $H < 0.8\ h$, which means that this wave will break at a depth of 2.5 m. To be on the safe side, the barriers should be positioned around a depth of 5m. With help of Navionics [5], this depth is estimated to be at 150 m offshore (see appendix C.1). A topic for further research is the ecological impact of harvesting at this offshore distance.

Harvesting boat design

Because designing and building a suitable harvesting solution takes too much time to be finished in this stage, the general layout of such a solution will be explained. As described in section 6.4, a harvesting boat with a barrier is a favoured method. An automatic way of harvesting seems the most efficient in this stage, therefore the use of a harvesting boat with a conveyor belt is recommended. A flow of sargassum will be transported onto the conveyor belt where the water can leak through the belt before it ends up in the boat. This boat can be a simple hollow barge. A rough sketch of the design is shown in figure 8.3.

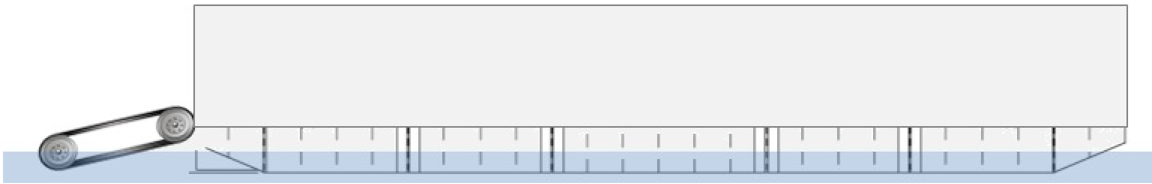


Figure 8.3: Containing barge with a conveyor belt

The expected total amount of sargassum for the considered 12 km of coast will be 1344 tonnes per day (equation 8.1). During this project sargassum samples from the sea have been taken and weighted (Appendix D.1), with these numbers an estimation for the density can be made: 12 kg of sargassum was harvested in a box with a volume of 0.14 m^2. The harvest boat will have to contain a much larger volume of sargassum, the extra weight will cause the sargassum to get more compacted, therefore an additional factor of 1.3 is assumed. With these assumptions, a density of approximately 105 kg/m^3 is gained. The volume flow in Cancún can thus be expected to be 12800 $m^3/\ day$.

A standard EUROPA 1 pushing barge has a deadweight of 1477 tonne and a volume capacity of 2660 m^3 should be emptied 5 times to harvest the total amount of sargassum. [1]

The barriers are used as a first protection method to give the harvesting boats some time to get in position and collect the sargassum in one place. Sargassum can lay a limited period against the barrier before it decays and sinks. There is no exact study established, but is assumed that this will happen after a couple of days. If sargassum is allowed to lay for one day next to the barrier, it will have a width of 7.6 m, here a height of 0.2 m is assumed. This means that a barge with a minimum conveyor belt width of 8 m would be sufficient to harvest the collected sargassum. The Europa I barge has a width of 10 m and can thus accommodate a sufficient conveyor belt.

Waterplant removers which work with the same collection method have a sail speed of 7 km/h, there is no additional information about the harvesting speed, and therefore this speed is assumed for the harvesting barge. When one harvesting barge with the dimensions of a

EUROPA I is used for collection, the harvest operation will take two hours of collecting and 5 hours of sailing.

8.3.3 Phase 3

The final phase starts at the moment that the total system has proven its working along the 12 km stretch in Cancún. With a working system it is easier to get funding for a bigger part of the coast. In the previous phase one harvesting barge was sufficient. At this point there is exact data available about the performance which will make it easier to determine the needed number and type of barges. Also from the barrier the week and strong properties will be known and where needed improved.

8.4 Processing implementation

The objective of this section is to develop a processing method to get a positive use out of the sargassum in the coming years. When burying of sargassum will be avoided, less nutrients will arrive in coastal water. This inhibits the extra sargassum growth in the coastal water of Mexico. The processing will propose a method to use the sargassum quantities arriving during golden tides as provided in the introduction of this chapter. Stage 1 will deal with the sargassum harvested around Cancún, in stage 3 the processing methods for the whole coast are implemented [8].

8.4.1 Phase 1

The first step is to improve the short-term processing with the already available methods. Burying sargassum should be avoided and the first implementations of converting sargassum to a fertilising supplement have proven their effectiveness. The process of creating fertiliser is relatively simple. For the composting market, available silos can be used which are normally used for other biomass sources.

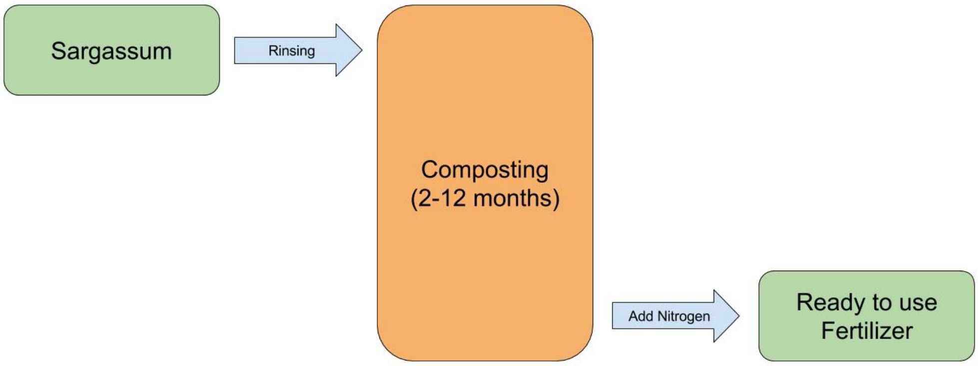


Figure 8.4: Fertiliser conversion process

8.4.2 Phase 2

When moving into second stage, there are possibilities for custom solutions. As mentioned before the key step in processing is to rinse and dry the sargassum to be able to store it. Sargassum can be a green alternative for fossil sources. To keep the end product as environmental friendly as possible, renewable sources will be preferred in processing. Looking at an area with an average temperature of above 25 C and rainfall above 100 mm per month in the months that sargassum arrivals are most common, this can be a realistic thought [4]. Coming to a solution like this will take time to develop. Figure 8.5 shows a preliminary design of how such a machine could work.

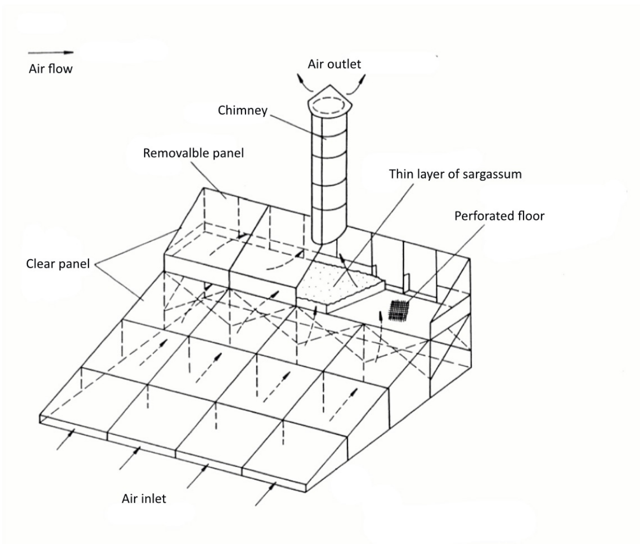


Figure 8.5: Solar air dry facility

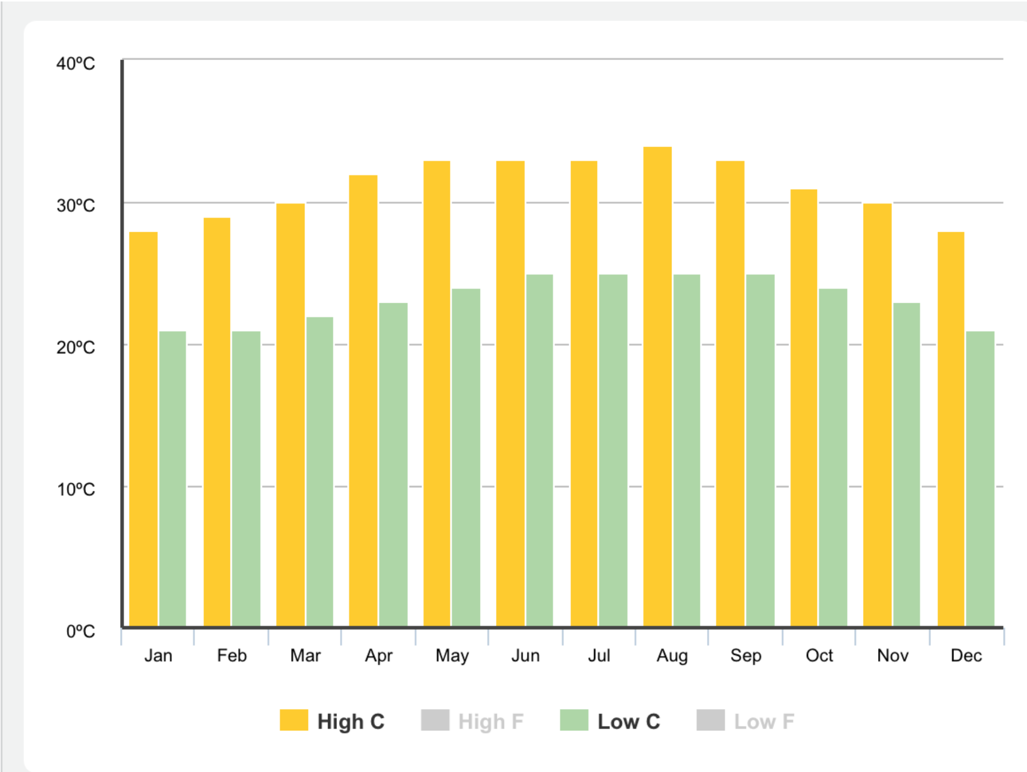


Figure 8.6: Average temperature Cancún [C]

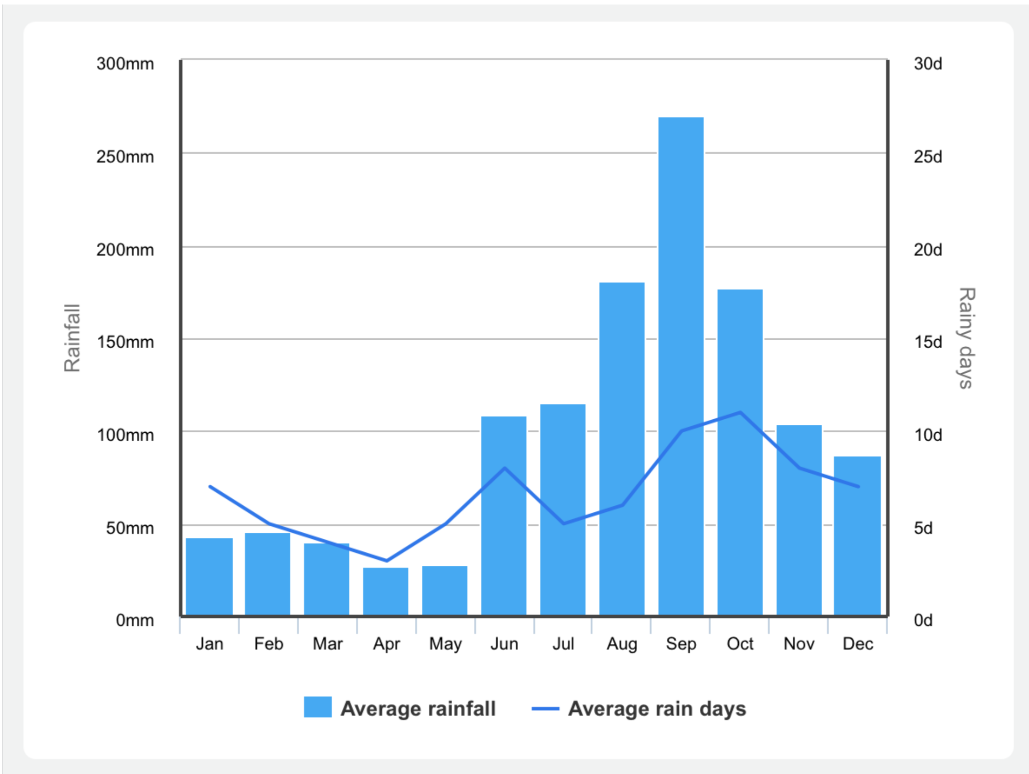


Figure 8.7: Average rainfall Cancún [mm]

Direct sun drying can change the material properties of the sargassum. It needs to be researched if this is a problem for further processing. There is a possibility to use solar energy for convective cooling. Picture 8.5 shows a system used for drying rice in Zimbabwe [9]. The sun heats up the ground, which in turn heat up the air. Warmer air tends to go up causing an upward airstream through the layer of sargassum. To be able to cope with the large quantities during golden tides the system can be scaled. Another upgrade would be to replace the fixed sargassum layer with a conveyor belt to create a continuous process.

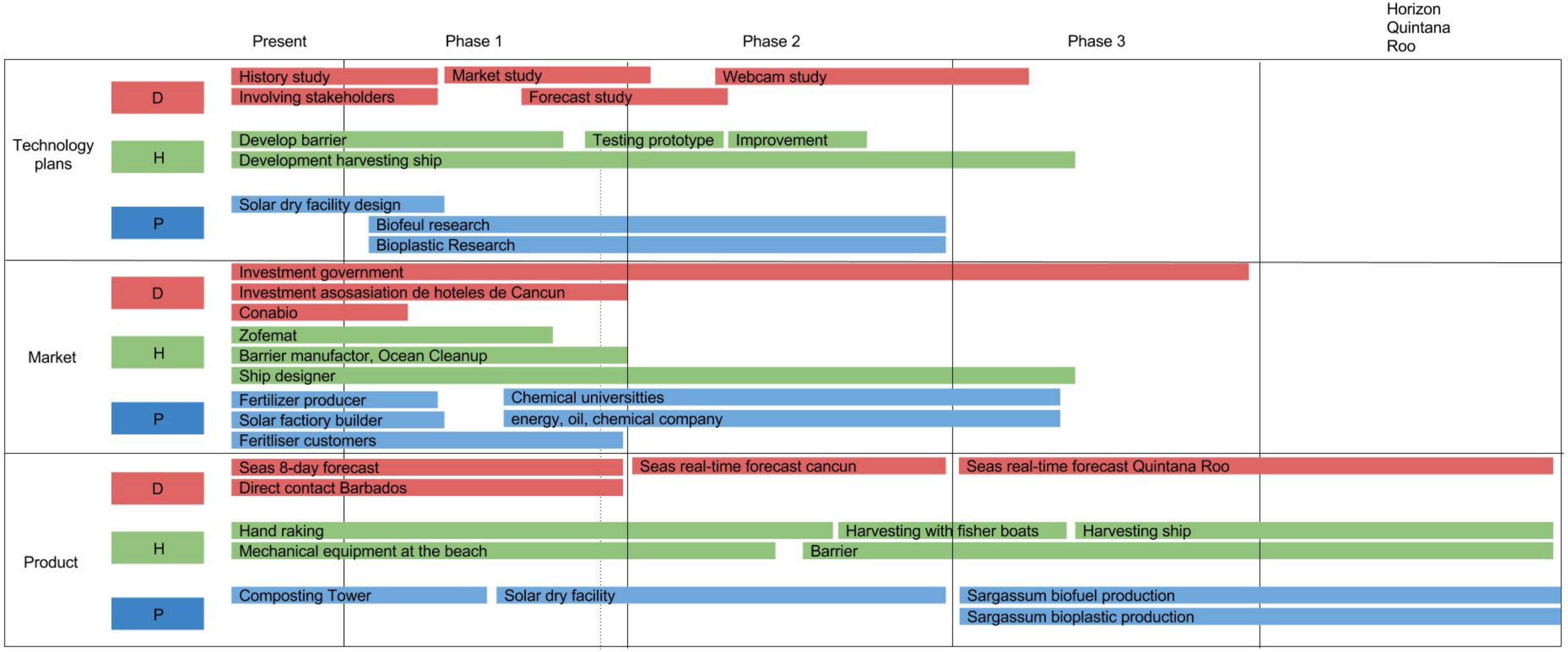
8.4.3 Phase 3

Phase 3 is the time to extend the the system with proven its effectiveness in phase 2 for drying to strategic places along the eastern coast of Mexico. With more time elapsed, sargassum biofuel or bioplastic conversion has a chance to be further developed.

Because the complexity is the processes, alliances with research institutes should be obtained. The European union has an ongoing project in the plastic production from seaweeds called SeaBioPlas [2]. For sargassum biofuel production there should be looked at the possibility to involve larger chemical or oil companies.

The Wageningen University in the Netherlands has a great expertise with the subject and Shell has experience in making ethanol from sugar cane in Brazil with their joint venture Razen [6].

8.5 Roadmap


Present
Phase 1
Phase 2
Phase 3
Horizon Quintana Roo
Technology plans
D
History study
Involving stakeholders
Market study
Forecast study
Webcam study
H
Develop barrier
Testing prototype
Improvement
Development harvesting ship
P
Solar dry facility design
Biofeul research
Bioplastic Research
Market
D
Investment government
Investment asosasiation de hoteles de Cancun
Conabio
H
Zofemat
Barrier manufactor, Ocean Cleanup
Ship designer
P
Fertilizer producer
Solar factory builder
Feritliser customers
Chemical universitties
energy, oil, chemical company
Product
D
Seas 8-day forecast
Direct contact Barbados
Seas real-time forecast cancun
Seas real-time forecast Quintana Roo
H
Hand raking
Mechanical equipment at the beach
Harvesting with fisher boats
Harvesting ship
Barrier
P
Composting Tower
Solar dry facility
Sargassum biofuel production
Sargassum bioplastic production

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Appendix A

Additional to chapter 1, 2, 3, 4

A.1 Langmuir circulation

On sea with a specific blend of wind and wave movement sargassum floats in a linear pattern on the water surface, the same as those foamy streaks of scum in harbours. This is due to the Langmuir circulation [5]. The Langmuir circulation is formed by wind blowing across the water surface, then convection cells begin to take shape. The surface water is pushed in a perpendicular fashion to the wind to create a circulation pattern below the water. Two rotating cells next to each other rotate in opposite direction.

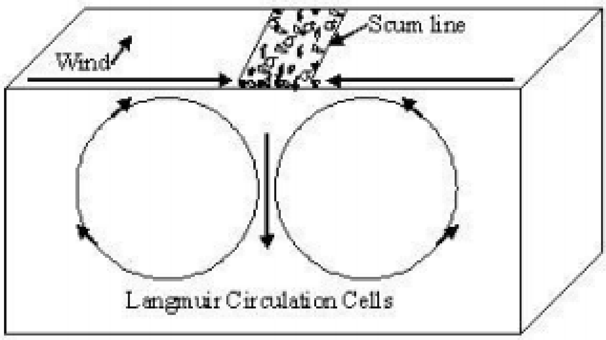

Figure A.1: The Langmuir Circulation sketched

A.2 Harvesting numbers

In this appendix all available harvesting numbers of the Secrets Resort & Spas (Cancún) beaches are displayed. All harvesting is done at the beach, manual or with a mini front-end loader. Not for every date data is available due to the absence of measurements.

Table A.1: 16 till 21 July 2015 (Daily) - Secrets Resort & Spas

Date	Manhours	Beach stretch (m)	Harvested sargassum (tons)	**Averaged (kg/m/d)**
16-7-2015	72	160	21	**131**
17-7-2015	72	220	27	**123**
18-7-2015	72	100	15	**150**
19-7-2015	72	130	21	**162**
20-7-2015	72	160	21	**131**
21-7-2015	72	80	15	**188**

Table A.2: 1 till 7 August 2015 (Daily) - Secrets Resort & Spas

Date	Used man hours	Collecting beach stretch (m)	Mass of harvested sargassum (tons)	**Averaged (kg/m/d)**
1-8-2015	48	210	12	**57**
2-8-2015	48	210	9	**43**
3-8-2015	48	90	9	**100**
4-8-2015	72	100	12	**120**
5-8-2015	60	120	6	**50**
6-8-2015	48	120	3	**25**
7-8-2015	48	120	3	**25**

Table A.3: 11 September till 20 October 2015 (Daily) - Secrets Resort & Spas

Date	Used man hours	Collecting beach stretch (m)	Mass of harvested sargassum (tons)	**Averaged (kg/m/d)**		Date	Used man hours	Collecting beach stretch (m)	Mass of harvested sargassum (tons)	**Averaged (kg/m/d)**
11-9-2015	60	80	16	**200**		1-10-2015	48	220	0,25	**1,1**
12-9-2015	60	80	18	**225**		2-10-2015	48	220	0,25	**1,1**
13-9-2015	48	50	15	**300**		3-10-2015	48	220	0,5	**2,3**
14-9-2015	48	80	21	**263**		4-10-2015	48	220	0,5	**2,3**
15-9-2015	48	120	6	**50**		5-10-2015	48	220	1	**4,5**
16-9-2015	60	120	2	**16,7**		6-10-2015	48	220	0,5	**2,3**
17-9-2015	60	120	1	**8,3**		7-10-2015	48	220	0,5	**2,3**
18-9-2015	60	120	3	**25**		8-10-2015	48	220	1	**4,5**
19-9-2015	48	120	1	**8,3**		9-10-2015	48	220	0,5	**2,3**
20-9-2015	48	120	0,5	**4,2**		10-10-2015	48	200	0,25	**1,3**
21-9-2015	48	120	0,5	**4,2**		11-10-2015	48	200	0,25	**1,3**
22-9-2015	48	120	1	**8,3**		12-10-2015	48	220	0,5	**2,3**
23-9-2015	48	220	0,5	**2,3**		13-10-2015	48	220	0,25	**1,1**
24-9-2015	48	220	1	**4,5**		14-10-2015	48	200	0,25	**1,3**
25-9-2015	48	220	0,25	**1,1**		15-10-2015	48	220	0,5	**2,3**
26-9-2015	48	220	1	**4,5**		16-10-2015	48	220	0,25	**1,1**
27-9-2015	48	220	1	**4,5**		17-10-2015	48	220	0,25	**1,1**
28-9-2015	48	220	1	**4,5**		18-10-2015	48	220	0,5	**2,3**
29-9-2015	48	220	0,5	**2,3**		19-10-2015	48	220	0,5	**2,3**
30-9-2015	48	220	0,25	**1,1**		20-10-2015	48	220	0,5	**2,3**

Table A.4: 21 October till 27 October 2015 (Daily) - Secrets Resort & Spas

Date	Used man hours	Collecting beach stretch (m)	Mass of harvested sargassum (tons)	**Averaged (kg/m/d)**
21-10-2015	48	220	0,5	**2,3**
22-10-2015	48	220	1	**4,5**
23-10-2015	48	220	0,5	**2,3**
24-10-2015	48	220	0,5	**2,3**
25-10-2015	48	220	0,25	**1,1**
26-10-2015	48	220	0,25	**1,1**
27-10-2015	48	220	0,25	**1,1**

Table A.5: November 2015 till August 2016 (Monthly) - Secrets Maroma

Date	Used man hours	Collecting beach stretch (m)	Mass of harvested sargassum (tons)	**Averaged (kg/m/d)**
nov-15	76	330	100	**10,1**
dec-15	Unkn	330	Unkn	**Unkn**
jan-16	93	330	95	**9,3**
feb-16	84	330	86	**9,3**
mrt-16	78	330	74	**7,2**
apr-16	78	330	60	**6,1**
mei-16	87	330	69	**6,7**
jun-16	Unkn	330	Unkn	**Unkn**
jul-16	90	330	55	**5,4**
aug-16	82	330	22	**2,2**

Table A.6: November 2015 till August 2016 (Monthly) - Secrets Capri

Date	Used man hours	Collecting beach stretch (m)	Mass of harvested sargassum (tons)	**Averaged (kg/m/d)**
nov-15	98	280	59	**7**
dec-15	150	280	114	**13,1**
jan-16	50	280	9	**1**
feb-16	101	280	10	**1,3**
mrt-16	93	280	49	**5,6**
apr-16	87	280	39	**4,6**
mei-16	48	280	17	**2**
jun-16	47	280	10,5	**1,3**
jul-16	48	280	4,6	**0,5**
aug-16	Unkn	280	Unkn	**Unkn**

Appendix B

Additional to chapter 5, 6, 7

B.1 MCA: Detection improvement

We, Coastal Seaweed Solutions, have conducted the multi criteria analysis. The multi criteria analysis is done in several steps in order to make a decision on which detection method functions best. First we have brainstormed on several criteria, which will be explained in appendix B.1.1. In this brainstorm session other less important criteria were dropped. In the second step we have ranked the criteria in order to distinguish the importance of the criteria. This is done in appendix B.1.2. In the third step we have validated the methods on the criteria, see appendix B.1.3. After this step a conclusion is drawn on which methods functions the best as a detection method.

B.1.1 Explanation of the criteria

1. Accuracy

   The accuracy of detection consists of 3 factors. Firstly, it depends on the location of the sargassum. Secondly, it includes the amount of sargassum in mass. Thirdly, it depends of its scale in square metre. It's an important criterion, because the better the accuracy the better predictions can be made and consequently better preparations can be done.

2. Forecasting time of landfall predictions

   The time between the sargassum detection and the landfall is the forecasting time. The earlier the prediction is known the better the preparations can be done. This is seen as the most important criterion, because this can change a reactive system to a proactive system.

3. Feedback

   When coastal managers receive the forecasts they should have the possibility to give feedback on the system after an event occurred. With feedback it can be determined if the forecasts were reliable. If not, the system can be improved which makes the system more reliable and more accurate after in time. The feedback is seen as an extra to the detection system, therefore it is not seen as important criterion.

4. CAPEX

   Capital expenditures. The capital expidentures may be high in case a working detection and forecast method can be bought. Furthermore, a detection method can be profitable, considering the many costs that can be saved. However it is somewhat important because it depends on what the client of the detection system is able to pay.

5. OPEX

   Operational expenditures. The same holds for the operational expenditures. These will propably not outweigh the costs that can be saved with a detection method. It is considered equally important as the capital expenditures.

6. Output

   The forecast information and/or the detection information of the sargassum is the output of the detection system. The way in which it is presented, values the output. Also additional information can be given, like wind speeds or currents, in order to improve the detection and forecast of the sargassum. It is considered as not very important, as long as the forecast of the sargassum landings are clear. The additional information is a nice bonus.

7. Applicability

   The possibility to apply the detection system on multiple locations. This is a very important criterion, because without it a detection development in another country will be pointless.

8. Update frequency

   The interested stakeholders along the coast are provided with detection information or forecast information. The update frequency means how many times per time period the interested stakeholders are receiving the information. It is considered not very important, as long as the interested stakeholders are warned on time.

B.1.2 Ranking of the criteria

Some criteria are more important than others, therefore each criterion has a weight factor on a scale from 0-1. The higher the weight factor the more important this criterion is. In table B.1 we have ranked the criteria. In this table the detection criteria are given in the first column and the first row. In the second row, criterion 1 "Accuracy of detection" is ranked with the other criteria. The ranking is done with values between 0-10. For example criterion 1 is 4 times less important that criterion 2 and criterion 1 is six times more important than criterion 3. If two criteria are equally important, both will be ranked with a 1. The values are summed per row and then divided by the number of criteria (8). This results in the weight factors, where 1 is the most important criteria and 0.06 the least important one.

Table B.1: Determining the weight factors for the detection criteria

	Accuracy of detection	Forecasting time of landfall predictions	Feedback	CAPEX	OPEX	Output	Applicability	Update frequency	**Weight factors**
Accuracy of detection	X	0,25	6	3	3	4	0,25	5	**0,60**
Forecasting time of landfall predictions	4	X	8	6	5	6	1	6	**1,00**
Feedback	0,167	0,125	X	0,333	0,333	0,5	0,167	0,5	**0,06**
CAPEX	0,333	0,167	3	X	1	2	0,2	2	**0,24**
OPEX	0,333	0,2	3	1	X	2	0,2	2	**0,24**
Output	0,25	0,167	2	0,5	0,5	X	0,25	2	**0,16**
Applicability	4	1	6	5	5	4	X	4	**0,81**
Update frequency	0,2	0,167	2	0,5	0,5	0,5	0,25	X	**0,11**

B.1.3 Validation of the methods

In table B.2 we have graded the current detection methods per criterion. The grades are between 1 and 10. The higher the grade the better the method. Then, the weight factors are multiplied with the grades. These values are summed per method, which results in the total score. The total score can be found in the lowest row. The higher the total score the better the method.

Table B.2: Validation of the detection methods

Criteria	Weight factor	Reactive	Texas A&M University Galveston	University of Florida	University of Southern Mississippi
Accuracy of detection	0,60	2	8	9	4
Forecasting time of landfall predictions	1,00	2	9	6	1
Feedback	0,06	1	6	1	8
CAPEX	0,24	10	2	4	9
OPEX	0,24	10	3	4	9
Output	0,16	1	7	10	3
Applicability	0,81	2	8	8	2
Update frequency	0,11	1	7	9	1
Total:		9,98	**23,7**	22,42	10.4

The reactive systems scores low on accuracy of detection, because the methods used for this are very inaccurate and consequently the forecasting time is very poor. The output of the detection is by communicated person-to-person and it lacks the possibility to feedback the system, therefore these criteria are validated low. Reason for the high grades of CAPEX of OPEX is that the system does not cost anything.

The SEAS system of Texas A&M University scores good on accuracy and forecasting time. It also provides the possibility to feedback the system. However, the costs are higher than the other systems. And, it has proven its applicability in other areas.

The SaWS system by the University of Florida scores higher on accuracy than SEAS, because the program methods are more developed. It scores lower on forecasting time, because only short-term forecasts are possible. The system does not have the possibility for feedback. The output is very well depicted on Google Earth and its applicable on the whole area of interest.

The University of Southern Mississippi has in its database the amount and location of the sargassum, therefore it score averaged on accuracy. It cannot be used for forecasts, but it can be used as feedback. The costs of this system are relatively cheap. The applicability is not recommended for other locations.

B.2 Harvesting at sea concepts

B.2.1 Water plant removal boat

In Puerto Morelos, a few water plant removal boats have been used during the golden tide in 2015. Normally, a water plant removal boat is used to remove excessive amounts of water plants in fresh water areas, it collects and transports water plants via a conveyer belt on the boat. Because there were not enough boats available to counteract the large influx of sargassum in Puerto Morelos, the exact efficiency of a water plant remover for the removal of large amounts of sargassum is not known. Since salt water can have a negative influence on the construction material and cooling system of fresh water purposed boats, adjustments to the original system are insuperable. An example of a concept boat that is based on the working of a water plant removal boat is the Sargaboat from the Ocean Cleaner, the sargassum passes between two foldable arms and is harvested by a conveyor belt (figure: B.2). Funding for a prototype is still ongoing [2].

Figure B.1: Water plant removal boat

Figure B.2: The Sargaboat [2]

B.2.2 Catamaran with a shovel

A new concept that has been developed is a catamaran with a shovel. This concept is designed during the golden tide in 2015. Because the influx of sargassum stopped before the funding and design were complete, the boat has never been used to remove large amounts of sargassum. At this moment the design will be further improved. See figure B.3 and figure B.4.

Figure B.3: Catamaran with a shovel removing sargassum

Figure B.4: New design harvesting boat with a shovel

B.2.3 Skimmer

Apart from boats, a skimmer can also be used as a remover method. A skimmer is a machine that removes oil during an oil spill operation. The working is shown in figure B.5. Because sand content in the water can destroy an oil spill pump, the oil skimmer pump needs to be adjusted for the removal of sargassum. DESMI a company that among other things is specialised in oil spill operations, has designed a machine that is based on the working of an oil skimmer: the Sea turtle DOP 250 (figure B.6). The sargassum flows through the skimmer where it is partially cut by cutting knives at the entrance of the screw [1]. The sargassum can be transported to land or to a boat by use of a long hose (figure B.7). To improve the efficiency of this method, the skimmer can be combined with barriers that collect the sargassum first. This collecting method will be explained in following subsection.

It is not known if the Sea turtle DOP 250 was capable of removing the sargassum and coping with sand contaminated flow, because DESMI is now working on a new removal unit that has a conveyer belt.

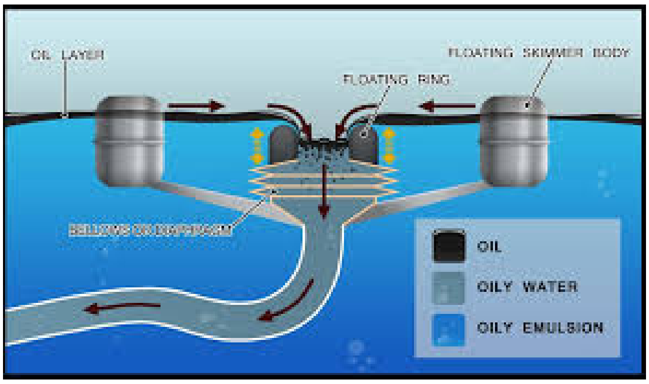

Figure B.5: The working of an oil skimmer

Figure B.6: DESMI: Sea turtle DOP 250

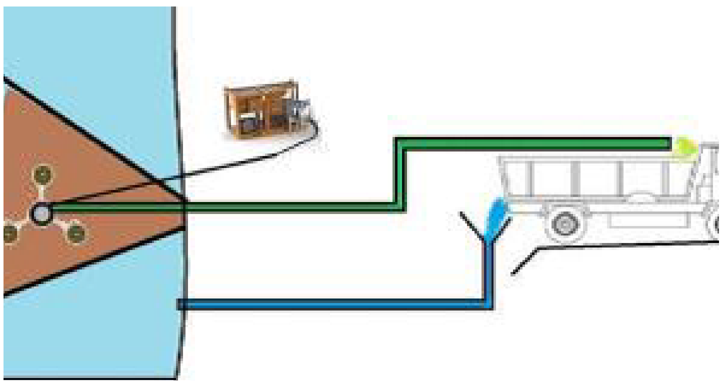

Figure B.7: Sea turtle skimmer with barrier and transport hose [3]

B.2.4 Additional collecting methods

To make the harvesting operation for a boat or skimmer more efficient, a collecting method such as a barrier can be used. A barrier contains sargassum against or near the barrier thereby preventing it to wash ashore. This is not a new technology as they are for example often used in oil spill operations and could play a key role in the removal of plastic debris in the ocean [4].

Containing barrier

A containing barrier is a system that physically stops the movement of sargassum and contains sargassum along the barrier. Some hotels already have experimented with a simple barrier, but this was not always working effective as can be seen in figure B.8.

Figure B.8: Unsuccessful barrier

Several companies have invented more sophisticated designs: there are inflatable barriers and barriers that consist of a submerged part and a floating part at the water surface (figures B.9 and B.10). The bottom of the barrier is not attached to the sea bottom, therefore marine life can still float under the barrier. Barriers can be used in calm, open and moving water, but it requires a different design per sea state though (stronger material, different anchoring etc.). It is not certain if these barriers have been used during large influxes of sargassum.

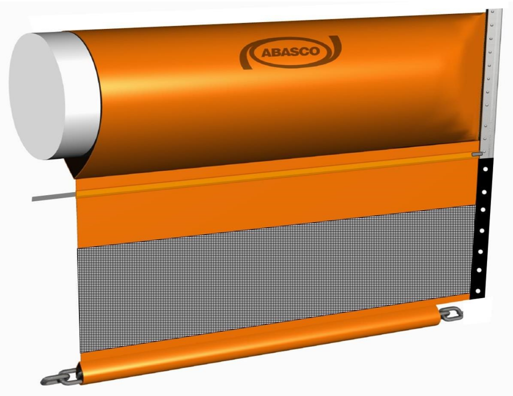

Figure B.9: Inflatable boom by DESMI

Figure B.10: Barrier with submerged part by ABASCO

When a barrier contains a large amount of sargassum that piles up against the barrier, the sargassum will be able to float under the barrier. Also when sargassum remains untreated it will decay and eventually sink to the bottom [3]. In that case sargassum cannot easily be removed anymore.

Reflecting barrier

Because a containing barrier was not always effective, Ocean Solutions Mexico has invented a reflecting barrier (figure B.11). This reflecting barrier is constructed of PVC tubes and does not contain or collect the sargassum directly. Due to its round form and stiff material it will reflect the incoming wave, thereby keeping the sargassum at distance. The use of a reflective barrier decreases the chance of accumulation against the barrier. The reflecting barrier has also not been tested in large amounts of sargassum yet.

Figure B.11: Reflecting barrier by Ocean Solutions Mexico

For both barriers a quick harvesting method is needed, since a raft of sargassum can block the sun and impact ecological life. Therefore both barriers shall never be used in areas with coral reef. When choosing a construction material some considerations have to be taken into account: The decaying process of sargassum generates hydrogen sulphates, this in addition to UV has impact on the strength of some common materials as PVC and lead [3].

B.3 Suggestions

B.3.1 Offshore boat

In general, a problem is solved best when it is solved close to its source. Therefore it seems logic to harvest sargassum offshore closer to its origin. Here sargassum is more concentrated in floating rafts while when sargassum approaches to shore it will proliferate and distribute itself along the coastline. Also, there are less limitations regarding ship dimensions offshore and therefore larger and thus less harvesting boats could be used. Harvesting offshore is thus more efficient than at the shoreface or at the beach and additional methods as beach poles and barriers are not necessary. Besides, the further sargassum is harvested offshore, the smaller the probability becomes that it will slip through and wash ashore.

On the other hand, as explained in paragraph 1.1.2, sargassum houses a lot of different species and has an important role in the eco-system. Offshore harvesting will thus have a significant impact on the environment.

Figure B.12: Boat for offshore harvesting

B.3.2 Beach poles

This new idea is meant to block the floating sargassum by means of beach poles. The beach poles are situated perpendicular to the coast. Sargassum is transported by the waves, which include littoral currents. There are littoral currents and there is littoral transport of sand and sargassum, because waves are coming in under an angle. This is the case in most situations, and it is rare if waves approach the beaches perpendicular. In figure B.13 this idea is sketched and the beach poles are indicated in red.

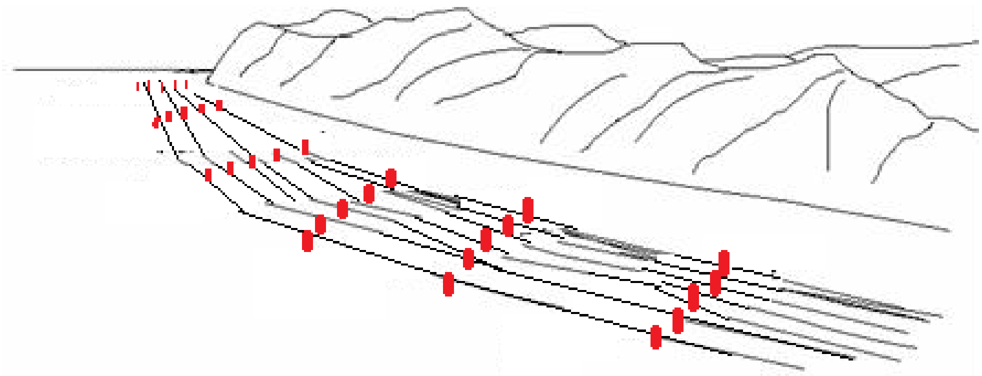

Figure B.13: Beach poles along the coastline

To improve the blocking of the littoral sargassum transport, floating barriers can be attached to the beach poles. These floating barriers can be inflatable or simple nets, which can be installed during a golden tide.

The beach poles do slightly reduce the littoral transport, which is required for this method. Hence, a few poles per row are needed. On the other hand, the beach poles also stabilise the coast due to this slight reduction of littoral drift and because they compact the sand. This is an additional plus, which even applies in normal conditions (no golden tides).

A more comprehensive technical study is needed for the feasibility of this method. The workability of this collecting method idea is shown in figure B.14.

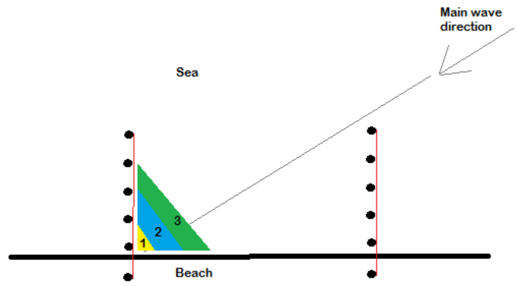

Figure B.14: Workability of the collecting method with beach poles

The main wave direction is given and waves will approach the beach accordingly. If the beach poles with the barriers collect the incoming sargassum, the sequence will be as depicted in the figure. First the yellow triangle will be filled with sargassum, consequently the blue and the green. The sargassum will eventually still wash ashore. Beach cleaning will still be needed but in less amounts, because with this method it is possible to collect the sargassum in the shallow waters as well by means of a boat. Therefore it will reduce the beach erosion, which is happening during the cleaning of the beaches.

B.4 MCA: Harvesting recommendation

The multi criteria analysis for harvesting is done in the same manner as the detection multi criteria analysis. For an explanation of this method, consult appendix B.1.

B.4.1 Explanation of the criteria

1. Ecological impact

   With ecological impact the direct impact on animals and plants is meant. The environment is not allowed to suffer from a harvesting method, therefore ecological impact is seen as the most important condition for a solution.

2. Beach erosion

   With beach erosion is meant the removal of sand on the beach during a harvest operation. Beach erosion is the biggest problem that is caused by the current removal methods. If the beach erodes, this will have a negative influence on the tourist industry and will cost a lot of money. This aspect is thus of high importance when choosing a harvesting method

3. Removal Capacity

   Removal capacity means if a method is capable of the removal of large amounts of sargassum. This project is about the search for a solution that solves the problems during a golden tide. Therefore a method that is not capable of harvesting large amounts is not sufficient.

4. Applicability

   Applicability means whether a method be applied in the area of interest. Some methods will have difficulty with governmental restrictions or environmental organizations and can therefore not be applied at each location. If a method cannot be applied, it means that there have to be searched for another solution. The applicability of a method has thus a large influence on the feasibiltiy.

5. Operability

   Apart from location, weather changes and sea states have also influence on the availability of a method. If a method cannot be put in operation, it means that there have to be searched for another solution. The operability of a method has thus a large influence on the feasibility.

6. Movability

   The movability of a method means if it can be moved quick to another area. For example if the weather changes, or if the cleaning of a specific area is fulfilled and the equipment has to be moved to a new area. The movability of a method has influence on the general efficiency. Efficiency is a valuable addition, but is not a condition for success or failing and therefore less important than the applicability or operability of a method.

7. Cleaning time

   How much time it takes to clean the beach or sea from sargassum. The cleaning time of a method has influence on the efficiency and is a valuable addition, but is not a condition for success or failing and therefore less important than the applicability or operability of a method.

8. Removing efficiency

   The chance that sargassum leaves behind on the beach or in the sea after the harvesting method is applied. The removing efficiency has influence on the general efficiency and is valuable addition, but is not a condition for success or failing and therefore less important than the applicability or operability of a method.

9. CAPEX

   Capital Expenditures. Normally, costs will never appear in an MCA, but there are no real numbers about the costs and the amount of removed sargassum, therefore it is not possible to make a cost-benefit analysis afterwards. Because costs are important (if a method has high purchase costs and cannot be afforded by the government or beach owners it can never be used), an estimation of the CAPEX have been made.

10. OPEX

    Operating Expenditures. Normally costs will never appear in an MCA, but because there are no real numbers about the costs and the amount of removed sargassum, it is not possible to make a cost-benefit analysis afterwards. Because costs are important (if a method cannot be executed because of high operational costs and cannot be afforded by the government or beach owners it can never be used), an estimation of the OPEX have been made.

11. Quality harvested sargassum

    Whether the harvested sargassum only consist of sargassum. Sand contamination can reduce the possibilities for processing methods. The quality of sargassum is important for the possibility of green uses. But is not a dealbreaker, since counteracting the large influx of sargassum is the first problem that has to be solved.

12. Labour intensity

    With labour intensity is meant the needed amount of manpower. A low amount of manpower can result in reduced operational costs which is good for the financial feasibility, but the need for manpower also creates employment, which is good for the economy. Because labour intensity can be seen as either positive or negative, this aspect is less important for the choice of a method.

13. Impact on tourism

    This means if the use of the method can have impact on the comfort of tourists. For example if the method is induces noise, landscape pollution, inaccessible areas etc.

B.4.2 Ranking of the criteria

The ranking of the harvesting criteria is done in the same manner as the ranking of the detection criteria. For an explanation of this method, consult appendix B.1.2.

Table B.3: Determining the weight factors for the harvesting criteria

	Ecological impact	Beach erosion	Removal Capacity	Applicability	Operability	Movability	Removing efficiency	Cleaning time	CAPEX	OPEX	Quality harvested sargassum	Labour intensity	Impact on tourism	**Weight factors**
Ecological impact	X	2	2	3	3	3	3	3	5	5	6	7	7	**1**
Beach erosion	0,5	X	1	2	2	3	3	3	5	5	5	6	6	**0,85**
Removal Capacity	0,5	1	X	2	2	3	3	3	5	5	5	6	6	**0,85**
Applicability	0,333	0,5	0,5	X	1	2	2	2	3	3	4	4	5	**0,56**
Operability	0,333	0,5	0,5	1	X	2	2	2	3	3	4	4	5	**0,56**
Movability	0,333	0,333	0,333	0,5	0,5	X	1	1	2	2	3	4	5	**0,41**
Removing efficiency	0,333	0,333	0,333	0,5	0,5	1	X	1	2	2	3	3	5	**0,39**
Cleaning time	0,333	0,333	0,333	0,5	0,5	1	1	X	2	2	3	4	5	**0,41**
CAPEX	0,2	0,2	0,2	0,333	0,333	0,5	0,5	0,5	X	1	2	3	3	**0,24**
OPEX	0,2	0,2	0,2	0,333	0,333	0,5	0,5	0,5	1	X	2	3	3	**0,24**
Quality harvested sargassum	0,167	0,2	0,2	0,25	0,25	0,333	0,333	0,333	0,5	0,5	X	2	3	**0,16**
Labour intensity	0,143	0,167	0,167	0,25	0,25	0,25	0,333	0,25	0,333	0,333	0,5	X	2	**0,10**
Impact on tourism	0,143	0,167	0,167	0,2	0,2	0,2	0,2	0,2	0,333	0,333	0,333	0,5	X	**0,06**

B.4.3 Validation of the methods

The validation of the harvesting methods is done in the same manner as the validation of the detection methods. For an explanation of this method, consult appendix B.1.3.

Table B.4: Validation of the harvesting methods

	Weight factor	Hand raking	Mechanical equipment on the beach	Harvesting boat in the surf zone	Boat with a barrier	Skimmer with barrier
Direct impact on wildlife	1	10	3	9	8	7
Beach erosion	0,85	3	3	10	10	10
Removal Capacity	0,85	1	8	6	8	5
Applicability	0,56	10	5	7	6	6
Operational window	0,56	9	8	8	7	7
Movability	0,41	10	9	8	6	5
Removing efficiency	0,39	1	8	4	9	6
Cleaning time	0,41	1	7	4	9	5
CAPEX	0,24	10	7	6	5	5
OPEX	0,24	7	8	6	7	6
Quality harvested sargassum	0,16	2	5	8	8	6
Labour intensity	0,10	1	8	6	8	7
Impact on Tourism	0,06	6	3	8	7	6
	Total score	33,74	34,62	42,66	**45,55**	38,07

As said in chapter 3, the benefits of manual cleaning on the beach are that it can be applied on all locations and the ecological environment is not much intruded. The equipment has a low CAPEX and is easy to move. Though, it leads to beach erosion, is time consuming and requires a large amount of labour which results in a higher OPEX. Because the harvest method is applied on the beach it will have small impact on the comfort of tourists who are at the beach as well. Also, the harvested sargassum will contain a severe amount of sand which will decrease the possibilities for processing.

Mechanical equipment is much more efficient than manual harvesting and therefore scores better on criteria that are related to efficiency. But this method is not always applicable as it has impact on the ecological environment. The CAPEX of mechanical equipment will be higher, but OPEX will be lower because less man power is required. As for manual harvesting, this method leads to beach erosion, low quality output and it has a high impact on the tourist industry because it will be a noisy operation.

Harvesting methods at sea do not cause beach erosion and will have less impact on the tourist industry as they are applied far from where tourists are. Harvesting at the shoreface will have the least impact on the environment and will be the easiest to apply, though it is less efficient and a lot of boats have to be used to ensure the sargassum will not wash ashore. The use of an additional barrier will increase the efficiency a lot, this reduces the OPEX but of course, will increase the CAPEX. Because a barrier can have an impact on the environment it cannot be applied anywhere. Due to anchoring this method has a reduced movability.

The use of a skimmer with a barrier will score the same on applicability and operational window as the method with a boat and barrier. Due to the installation of the hoses and skimmers, the amount of labour will be a bit higher than for the barrier. Because the sargassum is transported from the shoreface to the beach by means of a hose, this will have more impact on tourist industry. The workability of this method is not yet really known, therefore it scores average to low on efficiency.

Appendix C

Additional to chapter 8

C.1 Maps specific location

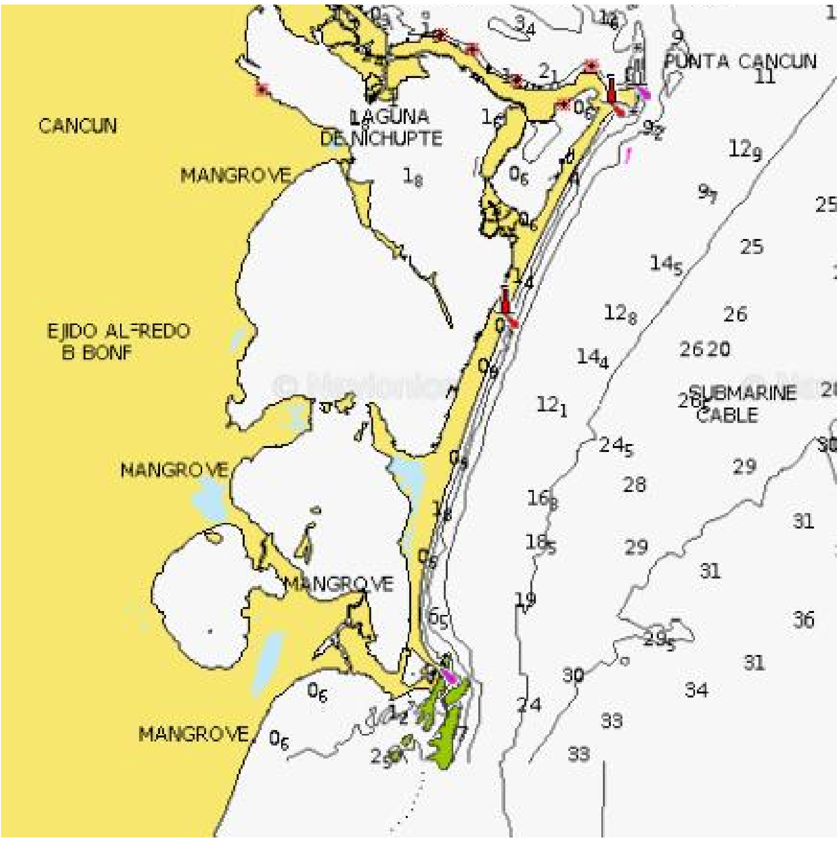

Figure C.1: Bathymetry Cancún

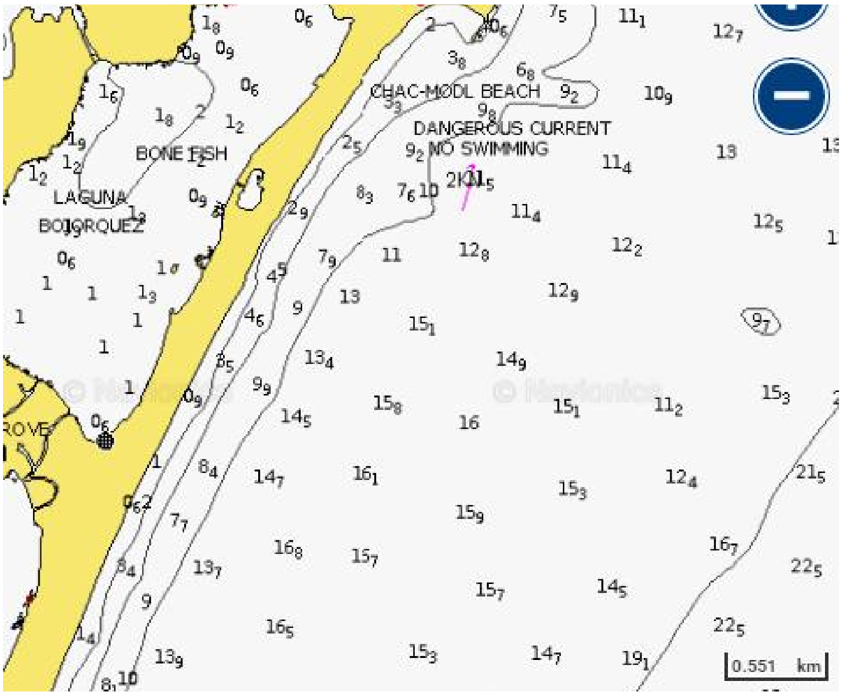

Figure C.2: Bathymetry Cancún zoomed in - 1

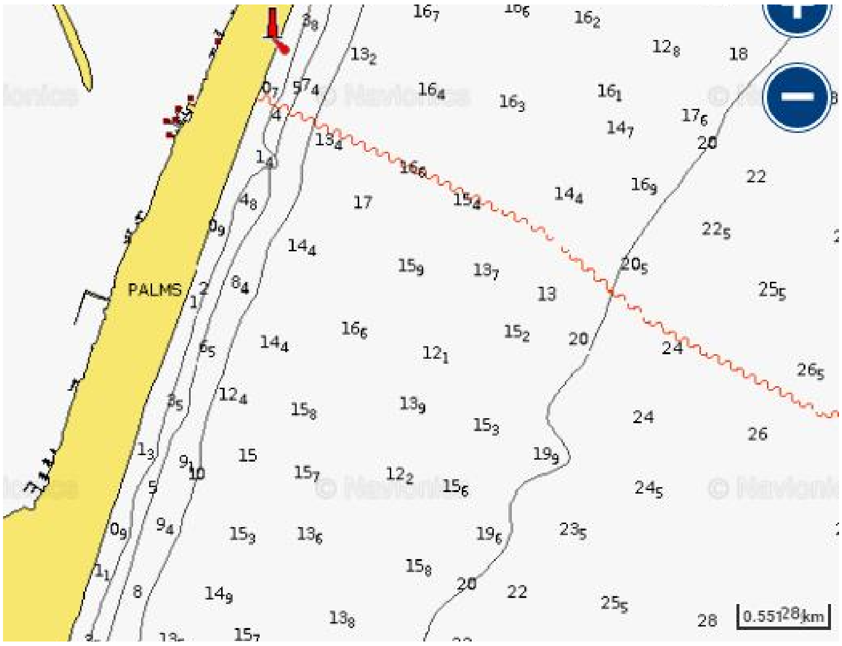

Figure C.3: Bathymetry Cancún zoomed in - 2

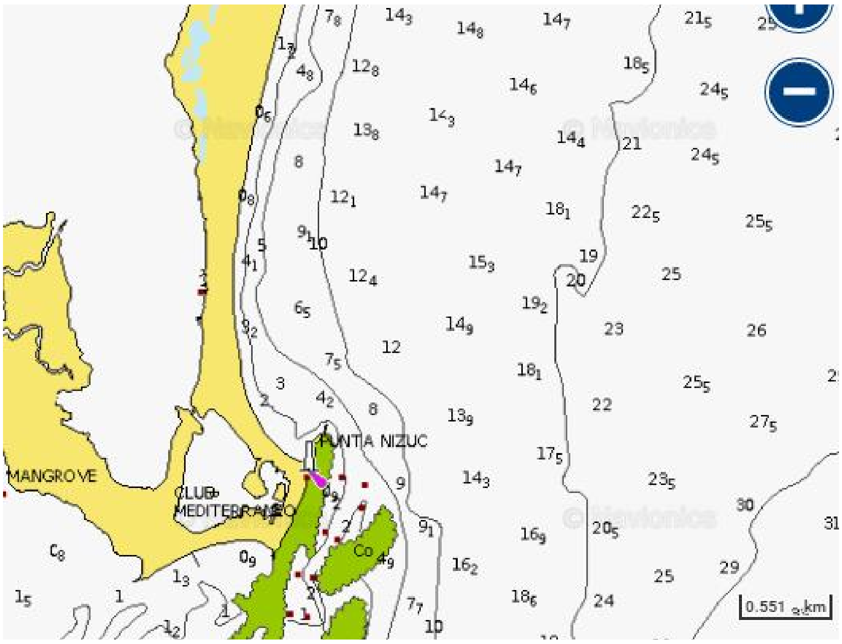

Figure C.4: Bathymetry Cancún zoomed in - 3

C.2 Wave conditions

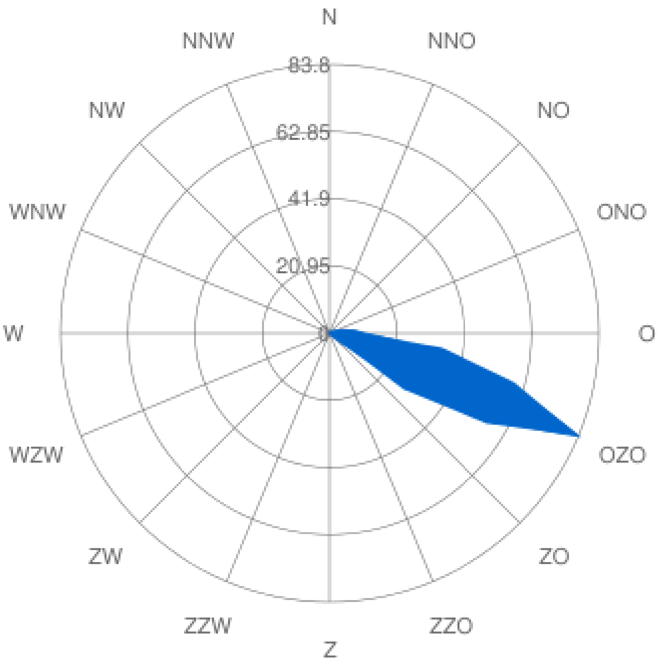

Figure C.5: Swell direction in June

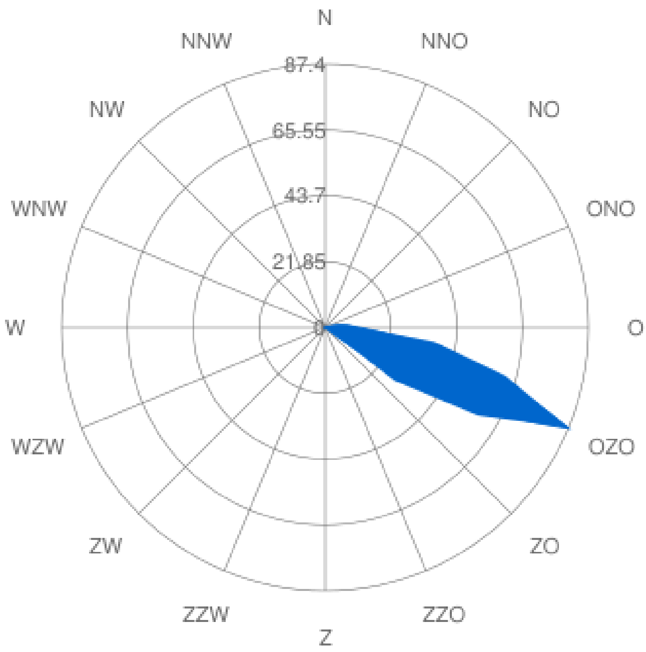

Figure C.6: Swell direction in July

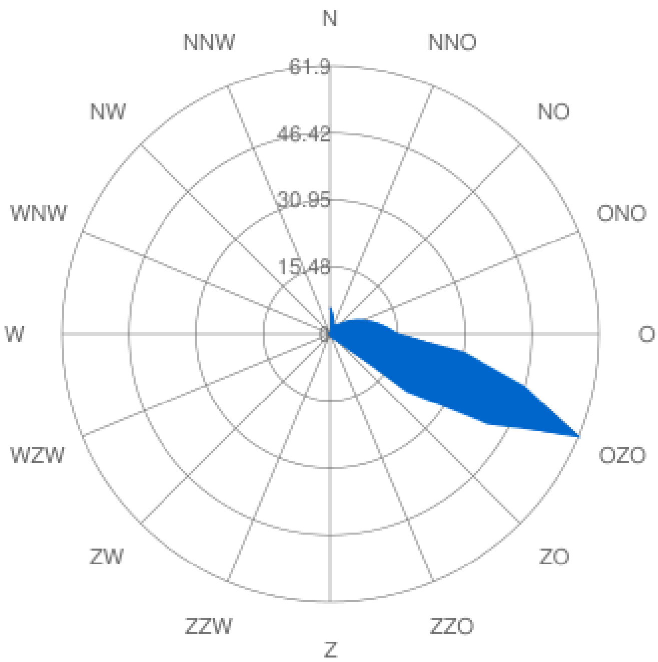

Figure C.7: Swell direction in August

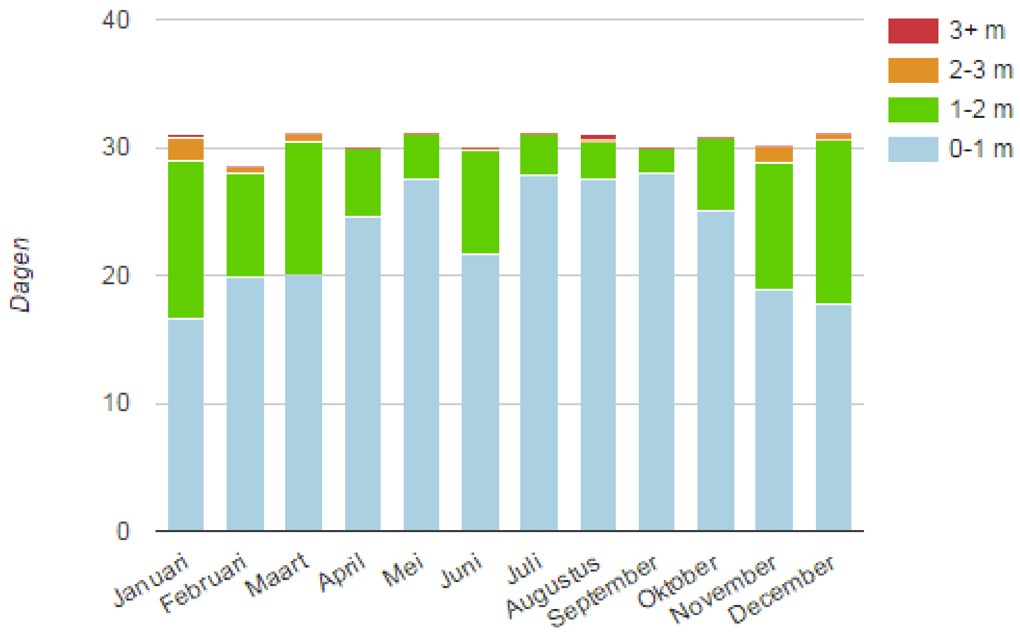

Figure C.8: Wave height

C.3 Wind conditions

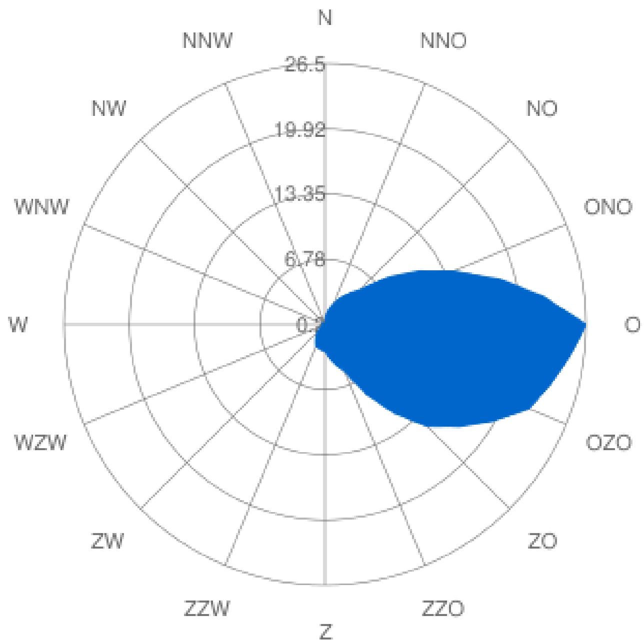

Figure C.9: Wind direction in June

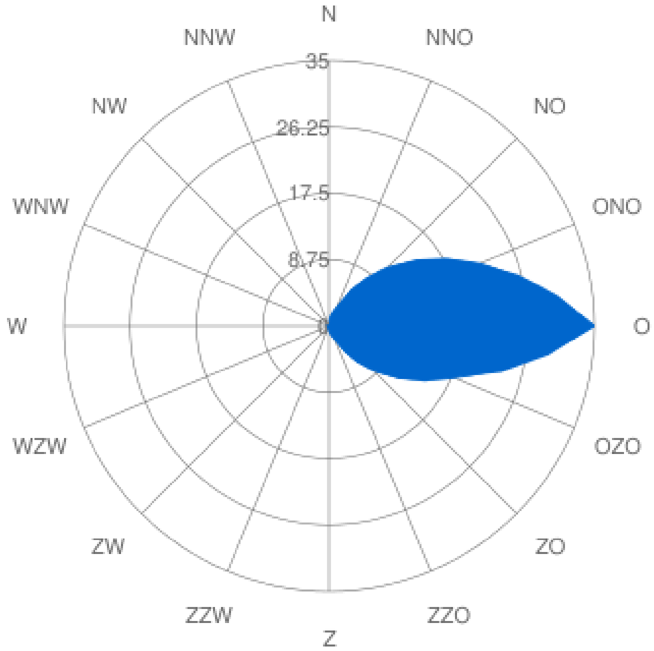

Figure C.10: Wind direction in July

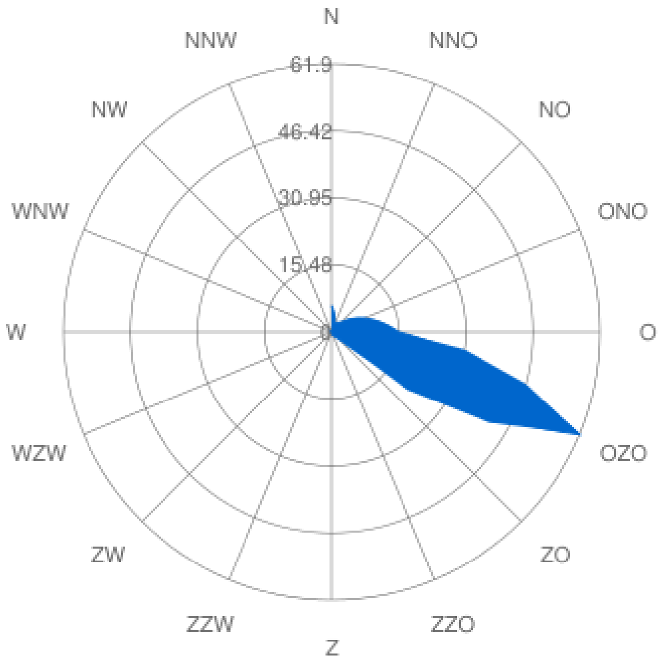

Figure C.11: Wind direction in August

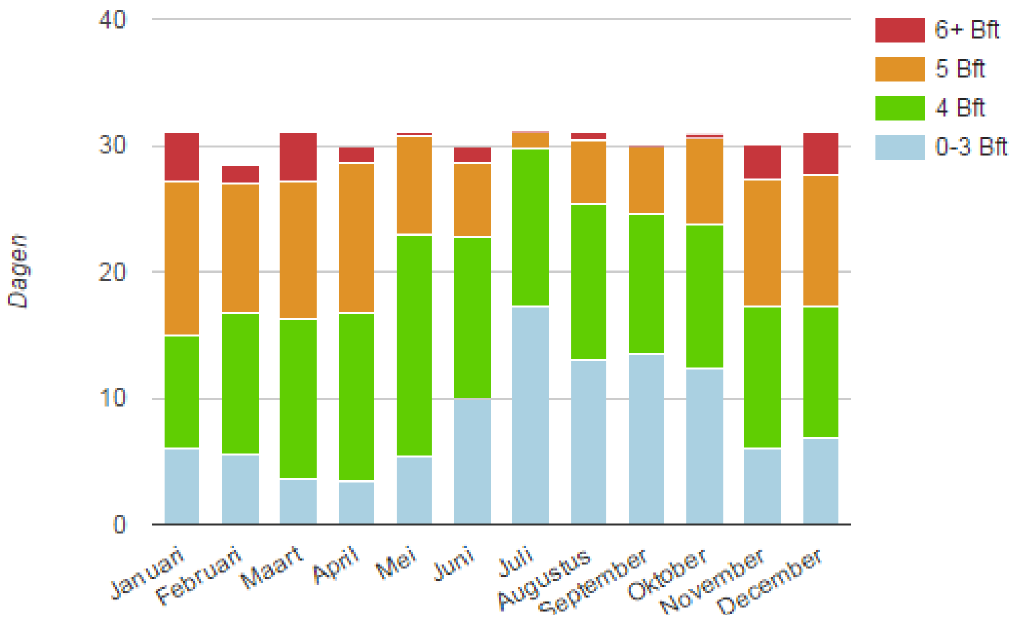

Figure C.12: Wind force in Beaufort

C.4 Harvesting Implementation

C.4.1 Golden tide numbers

Table C.1: Estimated flow of sargassum

Length coastline Cancún	12	km
Golden tide flow	200	kg/ m/ dag
Sand containment factor	0,2	
Estimated flow of sargassum sea	1920000	kg/dag
Estimated flow of sargassum sea	18288,8	m^3/ dag

Appendix D

Additional data

D.1 Sampling

In order to find out the real composition of the sargassum, two different samples are taken at the coast of Quintana Roo. One consisting of sargassum washed ashore near Tulum, the other consisting of sargassum floating at the shoreface of Puerto Morelos.

In table D.1 the wet and dry weights of both samples are shown and in table D.2 the density of the sampled sargassum is estimated.

Table D.1: Mass of samples

	Wet weight (g)	**Dry weight (g)**
Sample 1 (beach)	6858	2038
Sample 2 (sea)	11758	3341

Table D.2: Estimated density sargassum

Volume box	0,14	m^3
Weight sample sea	11,76	kg
Density sargassum wet	83,99	kg/m^3
Factor for compaction	1,25	
Estimated real density	105	kg/m^3

The following steps of the protocol are taken to collect the samples:

1. Harvest

While the protocol described to harvest around 50 whole plants, there was no opportunity to do so. A few whole plants are found together with a lot of small pieces. Both samples consist of as well *S. Fluitants* (approximately 90%) as *S. Natans* (approximately 10%).

2. Rinse

After harvesting the samples are rinsed and washed in sea water to remove debris and sand. Afterwards the samples were transported and hung for drip drying already on location. After drip drying the samples were measured for its wet weight.

3. Drying

For drying the samples are hung on clotheslines in a garage with openings in the walls and two fans in the corners. This way the samples were protected against direct sunlight. The beach- and sea sample had a drying time of respectively 19 days and 15 days.

4. Mill

For milling the samples a blender is used. This took some time, but worked out fine. After milling, the small pieces were spread out on a tarp in the garage for one more day.

5. Samples

Finally the samples are gathered in three plastic bags in three boxes. In this form the samples are ready for shipping to the Netherlands. The outcome of the analysis will be available after this research is finished.

Figure D.1: Harvesting sargassum in sea Puerto Morelos

Figure D.2: Harvesting sargassum on beach in Tulum

Figure D.3: Drying the sargassum

D.2 Hotel/Resort questionnaire

In order to get a clear view of the sargassum problem of the hotels and resorts along the coast of Quintana Roo, a questionnaire is developed and sent to all the hotels and resorts working together under the Asociacin de Hoteles.

The questions of the questionnaire and the responses (in Excel format) can be found on the next pages.

TU Delft

Boskalis Dragamex

Coastal Seaweed Solutions

Name of the hotel : Click here to enter text

Contact information : Click here to enter text.

Date : Click here to enter text.

General questions

1. **How often do large amounts of seaweed wash ashore?**
☐Daily, through the whole year ☐ Weekly ☐ Monthly
☐ Every 2/3 months ☐ Other: Click here to enter text.

2. **Is this a frequent or random pattern?**
☐ Random
☐ Depends per season. Frequent in seasons: Click here to enter text. ; Random in seasons: Click here to enter text.
☐ Frequent pattern with the frequency indicated above. In what/ which season(s) is the largest amount of seaweed expected? Click here to enter text.
☐ Other: Click here to enter text.

3. **Indicate which picture represents the beach the best when large amounts of seaweed have washed ashore:**


☐


☐


☐


☐


☐


☐

4. **Can you forecast when a large amount of seaweed is expected to wash ashore?**
☐ No
☐ Yes

5. **If question 4 is answered with yes, how is it forecasted and on what is does the forecast depend?** Click here to enter text.

Situation at the moment

1. **The amount of seaweed on the beach right now is (compared with the normal situation)**
☐ Very small ☐ Small ☐ Normal ☐ Large ☐ Very large

2. **Indicate which picture represents the current situation the best:**


☐

☐

☐

☐

☐

☐

3. **What is the type of seaweed lays on the beach in a normal situation? If more answers are true, wat was the ratio?**
☐ Marine grass ☐ Sargassum Fluitants ☐ Sargassum Natans
☐ Other: Click here to enter text.
Ratio: Click here to enter text./ Click here to enter text./ Click here to enter text.

4. **What were the types of seaweed that occurred during the bad year in 2015? If more answers are true, wat was the ratio?**
☐ Marine grass ☐ Sargassum Fluitants ☐ Sargassum Natans
☐ Other: Click here to enter text.
Ratio: Click here to enter text./ Click here to enter text./ Click here to enter text.

5. **What is/ are the type(s) of seaweed that cause the most nuisance?**
☐ Marine grass ☐ Sargassum Fluitants ☐ Sargassum Natans
☐ Other: Click here to enter text.

6. **Why?** Click here to enter text.

7. **What are the biggest nuisances? More answers are possible**
☐ Ugly view ☐ Smell ☐ Tourist complaints
☐ Other: Click here to enter text.

Current solution

1. **Does the hotel have a method to clean the beach? (More answers are possible)**
☐No ☐ Yes, by hand ☐ Yes, with chemicals
☐ Yes, with machinery ☐Other: Click here to enter text.

2. **Does the hotel have a method to harvest the seaweed in sea?**
☐No ☐ Yes, how? Click here to enter text.

If question 1 and 2 are answered with no, you can proceed to question 12

3. **What kind of equipment/ chemicals are used?**
Click here to enter text.

4. **Over what length/ area is the beach/ sea cleaned?**
Beach: Click here to enter text. [m] Sea: Click here to enter text. [m^2]

5. **Do you extend the cleaning beyond your own property lines? (Because for example the hotel is located next to a public beach or cooperates with another hotel)**
☐ No ☐ Yes, over what distance (in total): Click here to enter text.[m]

6. **Please fill in the amount of sargassum that is cleared away per day in a bad year (large amount of sargassum) and normal year with the monthly costs spent on cleaning.**

	Bad year	Normal year
Amount of sargassum per day [kg]	Click here to enter text.	Click here to enter text.
Monthly costs spent [US $]	Click here to enter text.	Click here to enter text.
Max monthly costs willing to spend on a future solution [US $]	Click here to enter text.	Click here to enter text.

7. **How often should the beach/ sea be cleaned?**
Beach: ☐ Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Never
Sea: ☐ Daily ☐ Weekly ☐ Monthly ☐ Yearly ☐ Never

8. **At what time of the day, the cleaning should be done best?**
☐ Morning ☐ Afternoon ☐ Evening ☐ Night ☐ Other:Click here to enter text.

9. **How long does it take to clean the beach/ Sea?**
Beach: ☐ Less than an hour ☐Click here to enter text.hours ☐Click here to enter text.days ☐Click here to enter text. Weeks
Sea: ☐ Less than an hour ☐Click here to enter text.hours ☐Click here to enter text.days ☐Click here to enter text. Weeks

10. **What are the advantages of the used method?**
Click here to enter text.

11. **What are the disadvantages of the used method?**
Click here to enter text.

12. **Do you have recommendations on a future solution to clean the beach/ ocean?**
Click here to enter text.

Processing

What happens with the seaweed after it has been harvested from the beach? (More answers are possible)

☐ Dumped ☐ Burned ☐ Food for animals
☐ Food for human's ☐ Bio energy ☐ Other: Click here to enter text.

1. **Is the hotel cooperating with another institute, company or hotel?**
☐ No ☐ Yes, which institute/ company or hotel? Click here to enter text.

2. **Does the government play a role in cleaning the beaches/ processing the sea weed?**
☐ No ☐ Financing ☐ Cleaning ☐ Finance and cleaning
☐Processing ☐ Finance and processing ☐ Other: Click here to enter text.

3. **Do you have recommendations on processing the seaweed into something useful?**
Click here to enter text.

Thank you for your time and help!

Please feel free to add any comments:

Click here to enter text.

CoastalSeaweedSolutions@gmail.com

Hotel	Contact information	date	How often do large amounts of seaweed wash ashore?	Is this a frequent or random pattern?	Which picture represents when large amounts of seaweed ?	Can you forecast when a large amount of seaweed is expected?	How is it forecasted?
Secrets Morema	Christopher Payne, Maribel Torres	24-aug	daily, through the whole year	Frequent		yes	
Royal Resorts, filled in by coworker in Playa del Carmen	npuente@royalresorts.com	29-aug	every 2/3 months	Frequent	6	no	
The Westin Resort & Spa Cancun	Nicolas Cejas	30-aug	Weekly/monthly	Random	4	no	
Desire Pearl Resort & Spa Riviera Maya	Alessio Giribaldi	2-sep	daily, through the whole year	Frequent, largest amount in september	5,6	no	
Azul Sensatori	Lic. Keila Cutz	8-sep	every 2/3 months	Random	6	no	
The Westin Lagunamar Ocean Resort Villas & Spa Cancun	Nicolas Cejas	30-aug	Weekly/monthly	Random	4	no	
Barcelo Tucancun Beach	SR. JESUS CAMPOS / DIRECTOR	1-sep	Monthly	Depends per season	3	no	
Paradisus Cancun	Angelica.cesena@melia.com	5-sep	All year but minimun, except during hurricane season	Depends per season	5	no	
Emporio Hotel & Suites Cancún	José Molina	1-sep	Daily	Random	3	no	
Ocean CoralL & Turquesa	Sr. GIOVANNI GIL y/o Sra. KENYA GUZMAN	13-sep	Daily May-Oct	May-Oct (Hurricaine season)	4	no	
Zoetry Paraiso de la Bonita	José Javier Chan/ Engineering Manager	12-sep	There is no definite pattern	Random	4	no	
Hotel Iberostar Cancun		13-sep	every 2/3 months	Random	2	no	

Hotel	The amount of seaweed on the beach now is?	Which picture represents the current situation best?	What is the type of seaweed lays on the beach in a normal situation? Ratio?	Types of seaweed occurred during the bad year in 2015? Ratio?
Secrets Morema	Normal			
Royal Resorts, filled in by coworker in Playa del Carmen	Normal	4	Sargassum Fluitants	Marine grass, Sargassum Fluitants
The Westin Resort & Spa Cancun	Small	2, 3		
Desire Pearl Resort & Spa Riviera Maya	Small	3	Sargassum Fluitants, Sargassum Natans	Marine grass, Sargassum Fluitants
Azul Sensatori	Normal	3	Marine grass, Sargassum Fluitants	Marine grass, Sargassum Fluitants, Sargassum Natans
The Westin Lagunamar Ocean Resort Villas & Spa Cancun	Small	2, 3		
Barcelo Tucancun Beach	Small	3	Marine grass	Marine grass
Paradisus Cancun	Normal	3	Marine grass, Sargassum Fluitants	Sargassum Fluitants
Emporio Hotel & Suites Cancún	Normal	3	Marine grass	Marine grass
Ocean CoralL & Turquesa	Normal	4	Sargassum Fluitants - 100%	
Zoetry Paraiso de la Bonita	Normal	3	Marine grass	Sargassum Fluitants
Hotel Iberostar Cancun	Small	2	Sargassum Fluitants	Don't know

What are the types that cause the most nuisance?	Why?	What are the biggest nuisances?
Sargassum	Smell	Smell
Sargassum Fluitants	Negative image, bad odor for breakdown of dead organic material	Smell, ugly view
Sargassum Fluitants		Smell, ugly view
Marine grass, Sargassum Fluitants, Sargassum Natans	Ugly view, smell and complaints	Ugly view, smell and complaints
Marine grass	For the cleanliness of the beach	Ugly view
Sargassum Fluitants		Smell, ugly view
Marine grass	-	Ugly view, smell and complaints
Sargassum Fluitants	It helps to proliferate Marine Flea which causes bad odor	Ugly view, smell and complaints
Marine grass, Sargassum Fluitants	For skin allergy wing bathers	Tourists complaints
Sargassum Fluitants	ALL INVADE AND EROSION THE BEACH, THE SAND IS LOST TO THE SEA. BAD ODOR	Ugly view, smell, complaints & swimmers void
Sargassum Fluitants	Because it´s very difficult swimm whit this type of seaweed	Smell
Sargassum Fluitants	Ugly view	Ugly view

Hotel	Is there a method to clean the beach?	Method to harvest the seaweed in sea?	What kind of equipment/ chemicals are used	Over what length/ area is the beach/ sea cleaned?		Do you extend the cleaning beyond your property lines?		Harvested amount of sargassum per day [kg] in a bad/ normal year		Monthly c[US $] in a bad/ n year
				Beach [m]	sea [m2]	No	Yes how	Bad	Normal	Bad
Secrets Morema	Sweeping (surf rake) and manual cleaning	No								
Royal Resorts, filled in by coworker in Playa del Carmen	Machinery and by hand	No		500		yes	300	18000	500	2000
The Westin Resort & Spa Cancun	By hand	No	Just mapower with rake and hands	300		no				3000
Desire Pearl Resort & Spa Riviera Maya	By hand	No		143		no			2200	212
Azul Sensatori	Machinery and by hand	No		440*25 *0.35	3850	no		1100	400	800
The Westin Lagunamar Ocean Resort Villas & Spa Cancun	By hand	No	Rake	300		no				3000
Barcelo Tucancun Beach	Machinery	No	Tractor	184*3		no		25	10	1000
Paradisus Cancun	By hand and machinery	No	Seaweed tractor	340		no		50	5	25538 M.N
Emporio Hotel & Suites Cancún	By hand	No				no		116000 year	58400 year	
Ocean CoralL & Turquesa	Machinery	No	Tractor with sargassum collector	860		no				5000
Zoetry Paraiso de la Bonita	Machinery	No	Sargassum sweeper	600		no		20000	1500	15000
Hotel Iberostar Cancun	Machinery	No	Machinery	400		no		10		1000

osts spent ... ormal	Max monthly costs willing to spend [US $] in a bad/ normal year		How often should the beach/ sea be cleaned?		At what time of the day, the cleaning is best?	How long does it take to clean?		Advantages of the used method?
Normal	Bad	Normal	Beach	Sea		Beach	Sea	
			daily		Morning	2 hours		Surf rake allows less manual work, is quick. When there is little Sargasso the cleaning can
1715	2571	1715	daily		Morning, afternoon	8 hours		Large amount of cleaning
2000	0	0	daily	daily	Morning, evening, night	4-6 hours		It is not invasive
35	70	25	daily	weekly	Morning	8 hours		Not the beach erodes, or compacted sand
500			daily	daily	Morning	1 day	3 days	Less sand in the process
2000			daily	daily	Morning, evening, night	4-6 hours		Not invasive
400	500	200	daily		Morning	2 hours		Keep clean the beach
360500000 M.N	25538 M.N	360500000 M.N	daily	never	Morning	Less than 1 hour		When we bury the seaweed we are creating a natural net to prevent a Coastal Erosion
			daily		Morning	8 hours		Having a healthy and clean environment
4000	5500	5000	daily		Morning	2 hours		IS FAST CLEAN
10000	5000	800	daily		Morning, afternoon	8 hours		It is not aggressive to the beach
	1000		daily		Morning	Less than 1 hour		Fast

Disadvantages of the used method?	Recommendations on a future solution for cleaning clean
Costs. Heavy equipment > pressure on the beach, bad for turtles nests	
Beach compactation, sand removal	floating barriers, efficient equipment on the beach
It takes longer than using a proper machine	It should be part of the authorities responsabilities to maintain the most importante asset of our destination in good conditions. I think that woud be a good idea use specific and approved
Takes a long time , it is not completely clean , it's a tiring job	
is very slow and tired	yes, because you damage the ecosystems less, use machinery Impacte less and save marine wildlife
Takes longer than machine	It should be part of the authorities responsabilities to maintain the most importante asset of our destination in good conditions. I think that woud be a good idea use specific and approved machines to clean the beach as part of the public cleanliness service.
none	Clean beach twice a day
Sometimes the shor	Aesthetically, the seaweed mixed with sand can make the beach look not clean.
It generates economic costs	The government should have a beach cleaning program especially seagrass, using machinery it and help the state tourism promotion.
COST	DOES HAVE ANTOHER METHOD, HANDING METHOD IS MORE SPENDING THAN THE TRACTOR
It is a little slow	No
Expensive	

Hotel	What happens with the seaweed after it has been harvested from the beach?	Is the hotel cooperating with another institute, company or hotel?	Does the government play a role in cleaning the beaches/ processing the sea weed?	Do you have recommendations on processing the seaweed into something useful?
Secrets Morema	Nothing	No	No	0
Royal Resorts, filled in by coworker in Playa del Carmen	Dumped	No	No	Compost or bio/energy
The Westin Resort & Spa Cancun	Dumped	No	No	It would be great if the sea weed could be converted in bio energy
Desire Pearl Resort & Spa Riviera Maya	Dumped	No	No	
Azul Sensatori	Food for humans and bio energy	No	No	yes , because produces bio energy and is sustaining
The Westin Lagunamar Ocean Resort Villas & Spa Cancun	Dumped	No	No	Convert in bio energy
Barcelo Tucancun Beach	Food for animals	Earth check/zofemat	No	continue on sand recycling
Paradisus Cancun	Naturally degrade in the sand	No	Goverment is in charge of clealing and processing all	It can be useful for compost, can be bury on the sand to prevent
Emporio Hotel & Suites Cancún	Buried in the sand	No	No	
Ocean CoralL & Turquesa	Dumped	No	No	BURY SARGASSUM TO PRODUCE SAND FOR THE BEACH
Zoetry Paraiso de la Bonita	Dumped	No	Watching the right way	
Hotel Iberostar Cancun	Dumped	No	No	

Hotel	Comments in general
Secrets Morema	
Royal Resorts, filled in by coworker in Playa del Carmen	
The Westin Resort & Spa Cancun	
Desire Pearl Resort & Spa Riviera Maya	
Azul Sensatori	The sargassun is not a problem , it is an alternative growth
The Westin Lagunamar Ocean Resort Villas & Spa Cancun	
Barcelo Tucancun Beach	
Paradisus Cancun	
Emporio Hotel & Suites Cancún	
Zoetry Paraiso de la Bonita	
Hotel Iberostar Cancun	

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