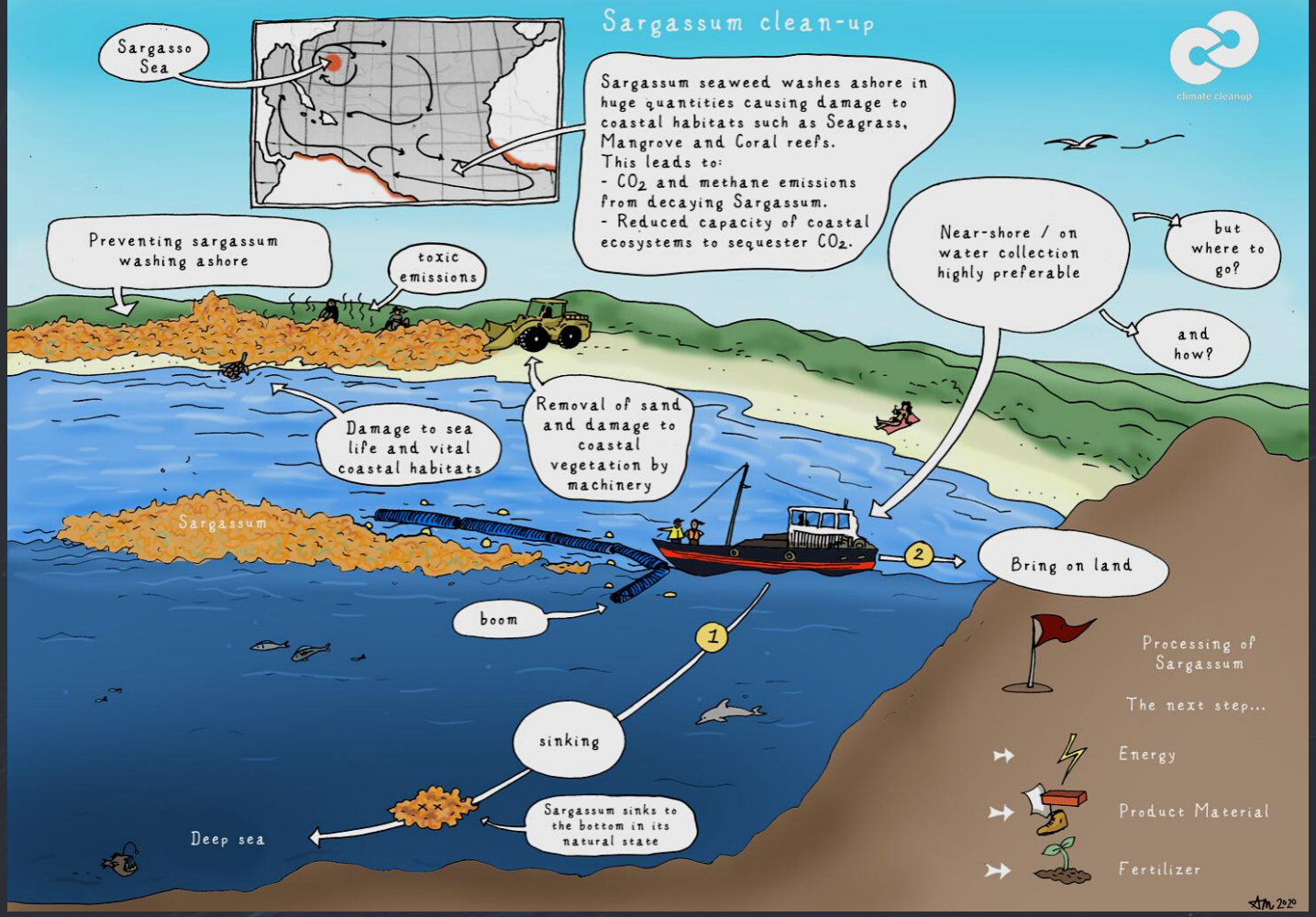


STICHTING
CLIMATECLEANUP.ORG

SARGASSUM CLEANUP

END-REPORT FOR THE MIIP018 FEASIBILITY STUDY


“A WICKED PROBLEM, CALLING FOR WICKED SOLUTIONS”



FOREWORD

To really reverse climate change, we as humanity need to both reduce emissions and remove 1500 gigaton of carbon dioxide. The potential of the oceans for removal has so far been largely overlooked. Seaweed (and other 'blue carbon' solutions), offers a huge untapped potential. N'Yeurt et al, quoted by Tim Flannery, have estimated that we can reverse climate change with, as an example, kelp cultivation on 9% of the ocean surface. It goes without saying when applying such solutions it is of the utmost importance to keep natural ecosystems intact and if needed to restore them. While this is an extremely large challenge, not all solutions have to come in the form of kelp, and not all solutions have to come from the oceans. But the order of magnitude is clear and the potential is huge.
The Sargassum phenomena poses a special position in this challenge....

Free floating Sargassum seaweed is blooming all over the Atlantic Ocean (the 'Great Atlantic Sargassum Belt') and washes up in great quantities on beaches and in bays in Mexico and the Caribbean region. Enormous volumes of seaweed cause still underestimated problems to ecosystems, economy and health. At the same time it offers golden opportunities for solving parts of the necessary puzzle, and even with emerging business cases. Finding solutions to the now local Sargassum problem enables us to find out how to unlock the potential of the oceans. We deal with questions like: How to protect coastal ecosystems from Sargassum? What does sinking seaweed do to the deep sea? How to handle seaweed off-shore? And it teaches us how to work holistically, in ecosystems that include not only marine life but also the social and economic context: all the people and organisations who are experiencing and connected to the oceans and life around it.

This report is an account of our attempt at connecting to these natural and human ecosystems, with the common goal of regenerating nature and reversing climate change. It is the challenge of our lifetimes. We sincerely hope, from the bottom of our hearts, that you will join.

On behalf of Climate Cleanup and the 1500 Club,
Bram Geers, Eelco Leemans, Fons Janssen, Peter Lindeman, Sven Jense



SUMMARY OF FINDINGS

In this summary we provide a brief overview of our findings and insights gained from the research done as part of the Sargassum Cleanup feasibility study. We do not intent to be, nor do we think we are complete. New studies and insights are coming available almost every day.
However, we do believe there is an important and overriding notion if we are really to look at the Sargassum problem as a 'Golden Tide': a more holistic view and approach is needed.
The ecological and economic aspects of Sargassum Seaweed inundating beaches and near shore coastal areas are underestimated. Not only beaches and tourism and human health are affected, but Sargassum is capable of smothering near-shore habitats such as Mangroves, Seagrass and Coral reefs extremely fast.
The value of these ecosystems, for biodiversity, our health, global and local economies is huge. With climate change and carbon sequestration in mind this means that focus should be directed towards the protection and restoration of these coastal ecosystems as they are even more potent than Sargassum Seaweed in taking up carbon, and that mitigation is key, avoiding Sargassum to beach, and ensure rapid collection when caught near-shore - using advanced monitoring and forecasting systems.
The Marine technology exists, however more attention should be given to multi-use and deployment as part of coastal protection, mitigation, and restoration efforts in a holistic approach. The size of the problem seems typically translated in the wrong manner, as volumes of Sargassum are highly dispersed over a large part of the Atlantic, and seasonal effects cause high levels of irregular supply, in space and time.
Valorisation is met with many challenges, Sargassum (fluitans and natans) are not comparable to edible and commercially grown seaweeds. Pathways of valorisation do not provide a straightforward scalable process dealing with large volumes of Sargassum, in particular on small islands affected by Sargassum inundating their beaches. High salt and ash content and levels of heavy metals such as Arsenic limit use and affordable processing.
Sinking Sargassum to the deep-sea ocean floor is technically feasible and can deal with large volumes. Sinking Sargassum seaweed mimics the natural process as found in the Sargasso Sea ecosystem and would not result in eutrophication or hypoxia. The volume of the blooming Sargassum which needs to be dealt with, and which would be eligible for sinking, is very small in context to size the deep-sea ocean floor and its ecosystems. Based on this we reason that the risk of fundamental negative ecological effects at deep sea floor level is minimal. For a license to operate legal and environmental acceptance needs to be obtained, through scientific research.

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MIIP018

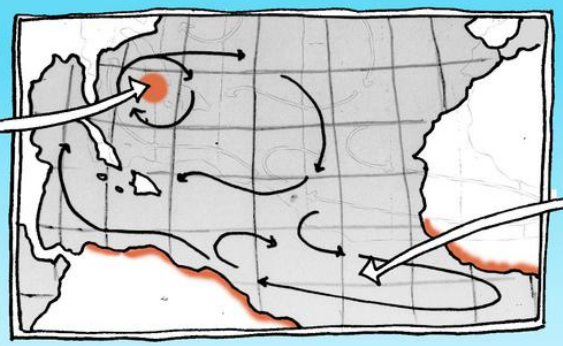
WHAT DID WE SET OUT TO DO?





Sargassum clean-up

climate cleanup



Sargasso Sea

Sargassum seaweed washes ashore in huge quantities causing damage to coastal habitats such as Seagrass, Mangrove and Coral reefs.
This leads to:
- CO_2 and methane emissions from decaying Sargassum.
- Reduced capacity of coastal ecosystems to sequester CO_2.

Preventing sargassum washing ashore

toxic emissions

Near-shore / on water collection highly preferable

but where to go?

and how?

Removal of sand and damage to coastal vegetation by machinery

Damage to sea life and vital coastal habitats

Sargassum

boom

1

2

Bring on land

sinking

Sargassum sinks to the bottom in its natural state

Deep sea

Processing of Sargassum

The next step...

Energy

Product Material

Fertilizer

AM 2020



CLIMATE CLEANUP

VISION OF CLIMATE CLEANUP

Vision on a nature based solution

WHY INVESTIGATE SARGASSUM SEAWEED

Sargassum seaweed plays a major role in the natural carbon cycle, specifically in the Sargasso Sea (the sea area located North from the recently created Greater Atlantic Sargassum Belt or GASB).
The seaweed that sinks naturally in the Sargasso Sea accounts for no less than 7% of the worldwide biological ocean carbon pump (source: Sargasso Sea Commission).
In the Sargasso Sea, the seaweed stays in place due to natural ocean gyresSince 2011, Sargassum has been blooming widely between West-Africa and the Caribbean. And since then, it has washed up in huge smothering mats on beaches in the Caribbean. So the question is: can we prevent this seaweed from further impacting Mexican, Caribbean and other coastlines with vital nursery habitats and coral reefs and at the same time develop a carbon pump similar to the natural pump in the Sargasso Sea?
In 2018 the Greater Atlantic Sargassum Belt did grow to over 20 million tons of Sargassum.

Our original idea was that if50% of this biomass could be sunk to the deep sea, biomimicking the lifecycle in the Sargasso Sea, this would potentially draw down an estimated 1 million tons of CO2 annually. This turned out a bit different....



INUNDATIONS OF SARGASSUM

Inundations of Sargassum seaweed (brown macroalga *Sargassum natans* and *Sargassum fluitans*) is a major problem for society and ecology in the greater Caribbean and the Gulf of Mexico.

The algae are considered a nuisance for the tourism industry and catastrophic to the ecology and environment. Vast volumes of beach cast mats of seaweed wash ashore and start to rot, degrade and stink, causing considerable impact to the local flora and fauna due to a toxic leachate. Tourism is the dominant economic industry, the effects from the decaying Sargassum are a serious threat to their business. There are also health issues associated with the gasses coming from decaying Sargassum piles on the beaches.
Concentrations of hydrogen sulfide exceed exposure limits and can exacerbate symptoms of people with asthma and other breathing problems.

The decomposition of this washed-up Sargassum causes a significant runoff of nutrients that results in a proliferation of algae growth, a reduction of the oxygen content in the water (Dissolved Oxygen), loss of mangrove forests, seagrass meadows, and coral reefs. This negative ecological impact is expected to continue at least until 2030 (Tussenbroek et al., 2017).

This also plays a role in the Dutch territories in the Caribbean, in particular: washing up on (often touristy) beaches, resulting in asphyxiation of marine life (both underwater and in mangrove forests), and the release of toxic hydrogen sulfide emissions as soon as the decay process takes place.



CAN SARGASSUM BE COLLECTED?

Can Sargassum be collected in large quantities before it washes ashore, without damaging marine life? What technical and marine opportunities are there to tackle this problem, with multiple positive impacts, for the environment and climate?

Various stakeholders, academic institutions and industries, includingthe hydraulic engineering sector, the University of Portsmouth, National Autonomous university of Mexico (UNAM) and the environmental Educational research center (MEER) are addressing the issue of washed-up and decaying seaweed on the beaches and coastal nursery habitats of Mexico and the Caribbean islands.

The Great Atlantic Sargassum Belt has been increasing over the years to a now 5,500 mile span, between West Africa and the Caribbean, causing significant ecological degradation due to the growing influx of nutrients flowing from African and South American rivers, probably aided by the warming ocean due to climate change.

The large increase in Sargassum seaweed and the washing up on coastal areas, beaches and mangrove forests has disastrous environmental consequences. Almost 80% of coastal species died due to the hypoxia and harmful leachate deriving from Sargassum(Rodriguez-Martinez at al. 2019). In addition, the water quality is significantly impacted as far as half a kilometer from the shore. The heavily reduced water quality has a vastly negative impact on important coral reefs (Rodriguez-Martinez at al. 2019) and other nursery habitats. Such impact will significantly damage the tourism trade, currently estimated at more than $22 billion US dollars in 2018.



OPTIONS AND OPPORTUNITIES

Seaweed is a well-known and promising climate solution (see also Project Drawdown).It captures CO2 quickly, because it grows fast (~ 5x as fast as land plants). Moreover, it does not compete for fresh water and agricultural land. With proper processing (e.g. use as material, soil conditioner and / or sinking) it can clear up large amounts of CO2.
If 9% of the oceans were arranged as a seaweed nursery, the climate problem could be solved in a few decades (N'Yeurt et al 2012). Sargassum seaweed specifically plays a major role in the natural CO2 cycle, namely in the Sargasso Sea (this is located to North of the recently created Greater Atlantic Sargassum Belt or GASB). The seaweed that sinks naturally in the Sargasso Sea accounts for no less than 7% of the worldwide biological ocean carbon pump (Sargasso Sea Commission). In the Sargassum Sea, the seaweed stays together due to natural currents. The GASB has now been growing widely between Africa and the Caribbean for about ten years and is now washing up Sargassum in huge smothering mats.
To summarize, this project started to find out how to prevent the algae from further impacting vital nursery habitats such as coral reefs and at the same time look at the development of carbon pump just like the one in the Sargasso Sea.

There are now 20 million tons of Sargassum growing in the Atlantic Ocean every year (and this is increasing). If 50% of this biomass is sunk in the deep sea, this could potentially draw down an estimated 1 million tons of CO2 annually.
Global developments in the field of Offshore activities, as well as the imminent decrease of activities in the fossil fuel industry, and only a very limited expansion of port areas for nature and environmental reasons need to be considered. Thus Sargassum may provide opportunities for the knowledge of Offshore and Marine technology to be used in different ways. Collecting and processing Sargassum Seaweed fits this potential. We set out to explore this together with project partner Van Oord.

Sargassum may therefore be the ideal seaweed for developing innovative carbon storage solutions.

Options identified:

- Sinking it into the deep ocean, quite literally creating a substantial "Carbon Sink"
- Processing into a responsible bio-based building material
- Processing into biomass or as a raw material for suitable applications.
- Processing into bioenergy



SARGASSUM CLEANUP

RESEARCH QUESTIONS

What were our main questions?

MARITIME INNOVATION IMPULSE

With this Maritime Innovation Impulse Project (MIIP018) - a feasibility study - our team and partners have tried to find answers to the following questions, which have received (too) little attention, yet provide globally-significant ecological effects and benefits, and may provide great opportunities:

- Which Marine Technological solutions are available to **collect** the Sargassum seaweed, that are **attainable, scalable, effective and environmentally friendly**?
- Which Marine Technological solutions are available to **use** the Sargassum seaweed in such a way that it can actually serve **as carbon sink**?
- What are the real possibilities to **process** collected Sargassum seaweed **as a biobased raw material or biomass**?
- What **effective infrastructure** is **needed to solve** the Sargassum seaweed problem?







SARGASSUM

SARGASSUM AND THE IMPORTANCE OF THE SARGASSO SEA



PELAGIC SARGASSUM SEAWEED

Sargassum fluitans and *Sargassum natans* are the species of seaweed causing inundations in the Caribbean and Mexican Gulf. These two species of Sargassum are unique in the fact that they are holopelagic, meaning staying afloat in the open ocean during their whole life cycle. They achieve this with small air bladders called vesicles. Sargassum is classified as a brown seaweed and originally comes from the Sargasso Sea. This sea area is noteworthy for the fact that it doesn't border any land and is defined by an ocean gyre (circulating ocean currents). Because Sargassum floats its entire life cycle, the whirling ocean gyre of the Sargasso Sea is ideal to grow in. The noteworthy presence of huge mats of Sargassum seaweed in the open ocean has been renowned ever since Columbus sailed through it. The overlap with the Bermuda triangle also shrouds it in mystery.

Open oceans in subtropical areas are usually rather devoid of life, being vast stretches of marine deserts. The Sargasso Sea however is full of life and is characterized as a very biodiverse marine area. What trees are to a forest, is what Sargassum is to the marine ecosystem of the Sargasso Sea. The mats of the golden brown seaweed provide food, shelter, and a foothold to a plethora of marine life. At least 10 species are endemic to Sargassum and 145 species of invertebrates, 127 species of fish and 30 species of whales are associated with Sargassum (Laffoley et al. 2011) Among them are the iconic fish species such as Atlantic bluefin tuna, swordfish, whale sharks, turtles and (critically) endangered European and American eels (IUCN red list).

All this biological activity is very relevant for the global climate as well.

The Sargasso Sea ecosystem acts as a large carbon pump that accounts for 7% of total global biological carbon sequestration. (Lomas et al. 2011). This makes the Sargasso Sea an incredibly underestimated ecosystem in terms of global climate, as well as biodiversity, and is something important to protect.





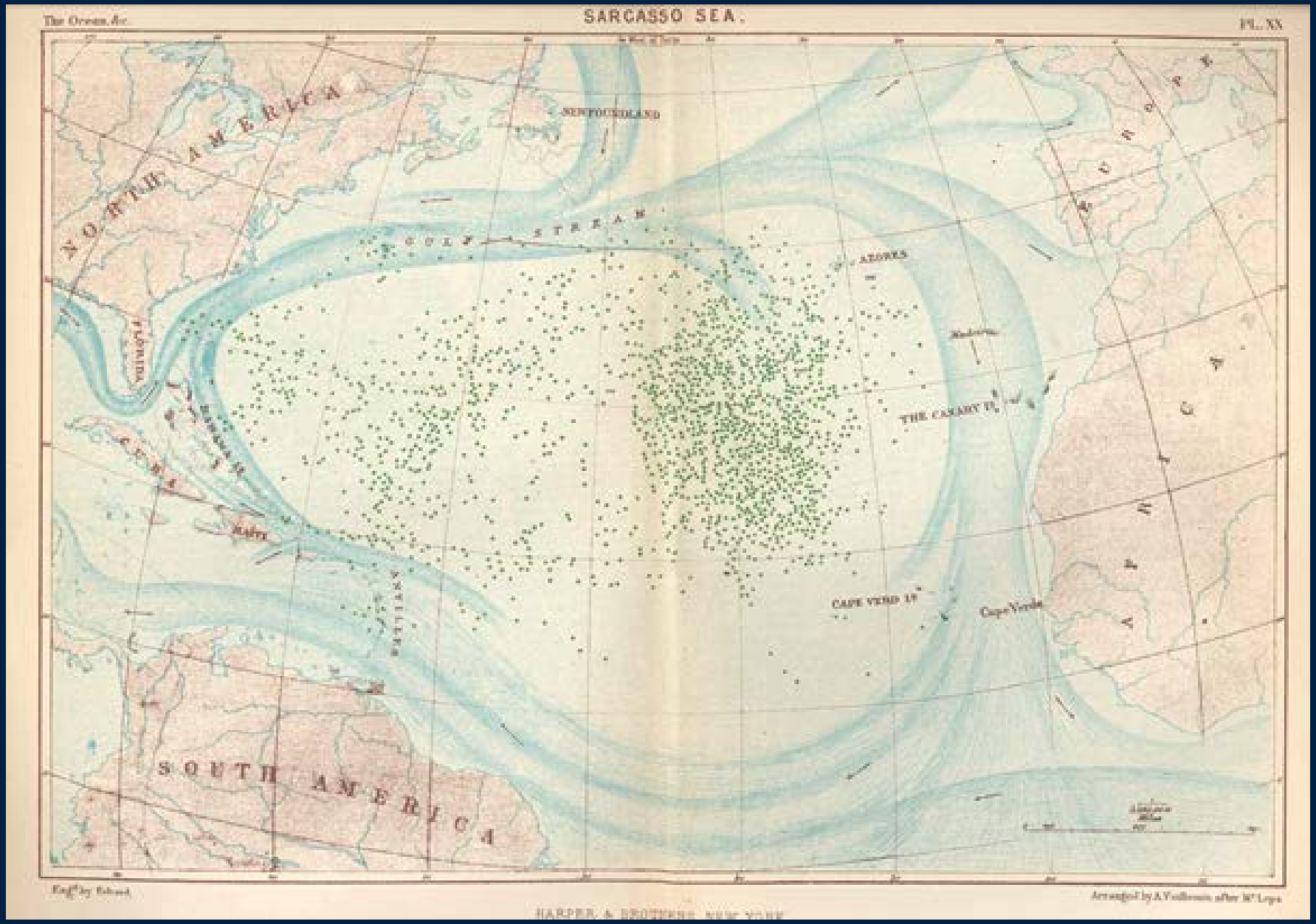
SARGASSUM PREDATOR

HISTRIO HISTRIO SCYLLAEA PELAGICA

Sargassum Frogfish
Photograph by Steve Walker
Scyllaea Pelagica
Photograph from inaturalist.org

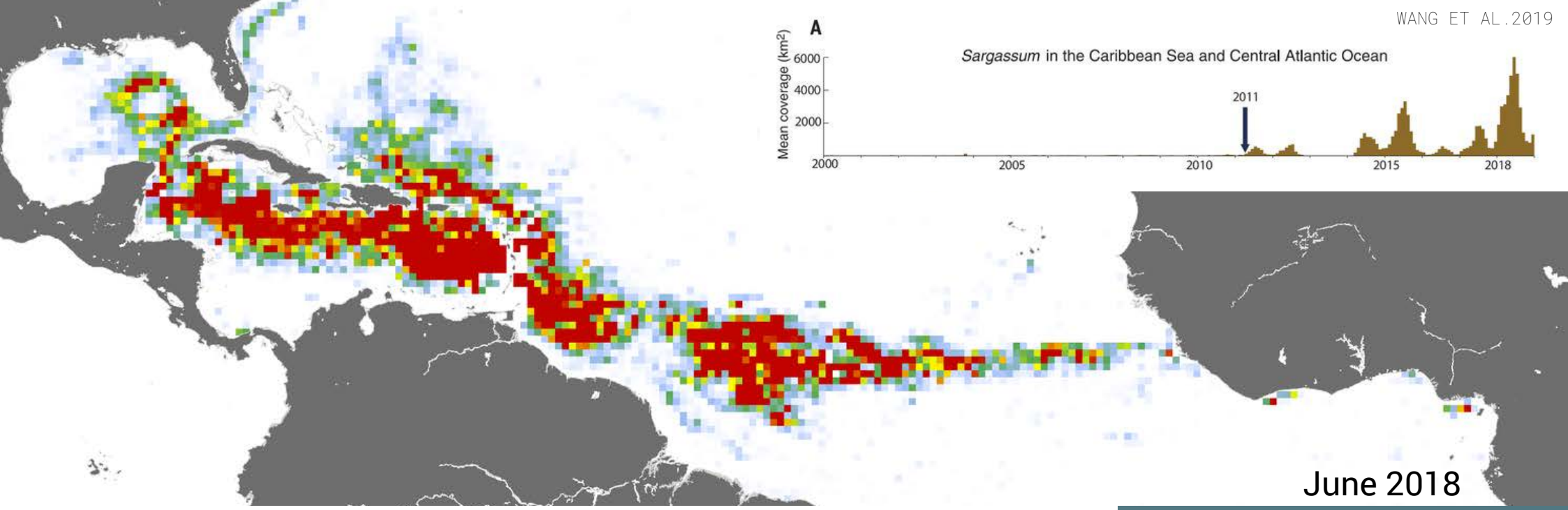
The **Sargassum Anglerfish or Frogfish, Histrio Histrio** is a species of fish fully adapted to the Sargassum Sea ecosystem where it mimics seaweed.
A voracious predator, endemic to the Sargassum habitat, is the Sargassum Angler Fish (Histrio Histrio), which has both camouflage and modified fins, which it uses to creep around the weed while waiting for passing prey.

The **Sargassum Slug or Scyllaea Pelagica**, with common name the Sargassum nudibranch, is a species of nudibranch, a marine gastropod mollusk in the family Scyllaeidae. This species lives among floating seaweed in the world's oceans, feeding on hydroids. This nudibranch is widespread in the central ocean basins, associated with drifting weed such as Sargassum bacciferum. It is green or brown in colour with scattered white patches. There are two pairs of lateral lobes, which are flattened and bear small branching gills on their upper sides. The whole body is irregular in profile providing good camouflage amongst floating Sargassum. The animal can swim upwards by flexing its body vigorously, an important ability for a nudibranch which drifts about the oceans.



SARGASSO SEA

MAP OF THE SARGASSO SEA FROM 1873



Until 2011 Sargassum was only found sporadically outside the ocean gyre of the Sargasso Sea. After 2011 blooms of Sargassum started to appear in an area stretching 8850km from West Africa to the Mexican Gulf this area is now known as the Great Atlantic Sargassum Belt (GASB). The record year of 2018 yielded 20Mt of Sargassum biomass.

With almost a decade of these blooms scientists are beginning to understand what has led to these annual blooms. It appears that a series of extreme weather events led to the seeding of Sargassum into the North Equatorial Current (area of the GASB). However the subsequent excessive growth of the biomass of Sargassum has been linked to changes in sea surface temperatures and increased atmospheric CO2 concentrations. Most importantly it is linked to excess of nutrients (eutrophication) caused by Saharan dust and nutrient runoff from rivers like the Amazon and Congo river. Nutrient runoff is mostly anthropogenic as deforestation and increased fertilizer use on land releases massive amounts of nutrients in the ocean. At the Amazon river mouth now exists a year round patch of Sargassum called the "Small Sargasso Sea". Most important drivers for Sargassum blooms seem to be iron and phosphate.

While not all factors driving these blooms are fully understood, most scientist agree these annual Sargassum blooms are here to stay for coming decades.

ORIGIN OF BLOOMS

Creation of the
Great Atlantic Sargassum Belt(GASB)



Sargassum inundations are problematic to the tourism industry which is the most important economic activity in the Caribbean area. When Sargassum rafts wash ashore it can sometimes pile up to 3 meters. Aside from making an unappealing sight for beach loving tourists it attracts sand fleas, makes swimming and boating difficult.
Then there is the smell of rotten eggs, this is caused by hydrogen sulfide gas being produced by the decaying seaweed. This gas is more than a nuisance as it is highly toxic, the gas even exceeds occupational exposure standards (OES) of 5ppm also impacting local residents **Health impacts are only recently becoming clearer. Resiere et al. 2020 show that Sargassum inundations cause neurological (80%), digestive (77%) and respiratory (69%) disorders.**

The economic effects of Sargassum on the Caribbean area are huge as the area is known as **"the most tourism-dependent region in the world"** which generated an income of **$59 billion** in 2019 (WTTC). As highlighted further in this report Sargassum also has a big impact on ecosystems. The ecosystems that are impacted are vital to the area as they provide coastal protection by reducing wave energy. And perhaps most importantly these ecosystems form the base of marine food webs thus also of fisheries. In conclusion: the beautiful clear waters and **abundance of sea life** associated with coral reefs, sea grasses and mangroves **is what drives tourists to come in the first place**.

TOURISM & HEALTH & ECONOMY

Impact







SINT MAARTEN

A TRIP TO COLLECT SARGASSUM











SARGASSUM CLEANUP

COLLECTING IN SINT MAARTEN

An expedition

Many of the pictures in this report were made while on Sint Maarten where we travelled from 31st of August until the 15th of September 2020. The most efficient way to learn was through real world experience: how to effectively collect and dry the Sargassum. For our experiments planned in The Netherlands, such as gasification, anaerobic digestion, paper production and composting,we estimated a need for 150 Kg of dried Sargassum. This meant harvesting some 1500Kg of fresh Sargassum! We wanted to learn more about the biology and ecology of Sint-Maarten and the effects that Sargassum has. We also wanted to gain insights from local partners and stakeholders on social, economic and environmental aspects. This we all managed to do, and even a little more!

Planning for a trip to collect Sargassum immediately confronted us with the seasonality of the Sargassum problem. Because we partnered with STINAPA Bonaire we thought we would go to Bonaire. However when we finally wanted to travel there, no Sargassum was available there. Luckily we we're introduced to Nature Foundation Sint Maarten and their incredible team. They have supported us in the best way possible. Way more than we had imagined when we embarked on this journey. Thank you!!!

The next page will show some more pictures from our trip and activities. A full 'log' can be visited on: https://www.polarsteps.com/PeterLindeman5/3731575-sargassum-st-maarten




THE STORY OF CAPTAIN SCOUT OF THE BLACK TURTLE

























SLS
ST. MAARTEN
LABORATORY
SERVICES








Heavenly










FRAGILE
FRAGILE
FRAGILE


Marigot





ECOLOGICAL EFFECTS

CONSIDERATIONS AND INSIGHTS





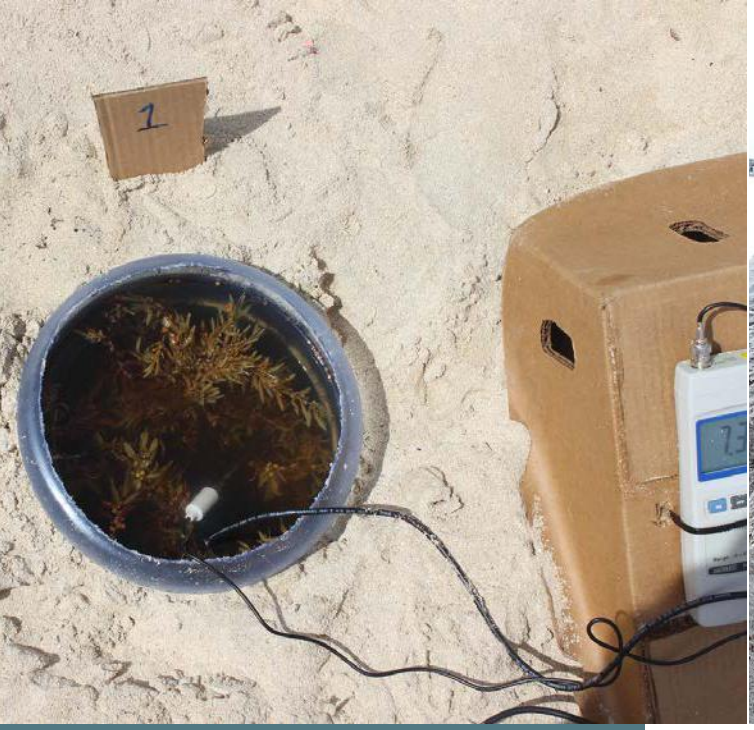


We have learned from the many science reports, journal articles and ecologists that we've spoken to that Sargassum in coastal areas is a big problem. However most of them also perceive Sargassum in the open ocean as positive, or neutral at a minimum. In the open ocean Sargassum does not degrade and exude toxic leachate, nor does it turn the environment hypoxic.
The little negative impact associated with Sargassum in the open ocean is down to large water columns, and the vast area Sargassum is able to spread over.And as is the case in the Sargasso Sea, pelagic Sargassum does support life in open oceans. Furthermore, Sargassum seaweed is presumed to be caused by eutrophication, warming sea temperatures and increased atmospheric carbon levels. When Sargassum is removed from the open ocean while these factors remain one can expect another (invasive) species to bloom excessively.

Dutch Caribbean Nature Alliance (DCNA): Prevention and Cleanup of Sargassum in the Dutch Caribbean: *Collection of Sargassum in the open ocean is not recommended. (..) this would remove the ecological value of Sargassum at sea and endanger the species associated with the seaweed rafts. According to Hinds et al. (2016), "by the time the Sargassum rafts are very close to stranding, the majority of associated organisms have already abandoned the raft, or wash ashore" (Hinds et al., 2016).*
However, recent studies show that effects on coastal ecosystems are much more devastating than previously assumed *(Hendy et. al., 2021, under review).*

CONSIDERING ECOLOGICAL EFFECTS

More research is coming







SARGASSUM CLEANUP

BEACHING SIMULATION EXPERIMENT

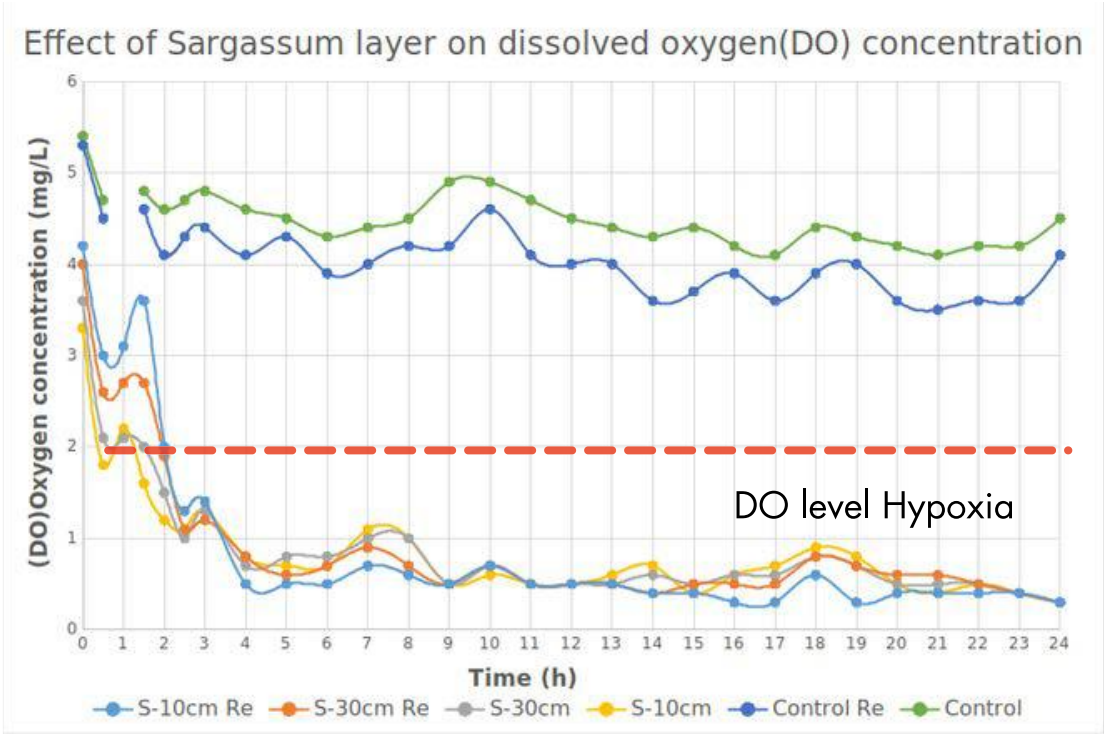
Sint Maarten expedition

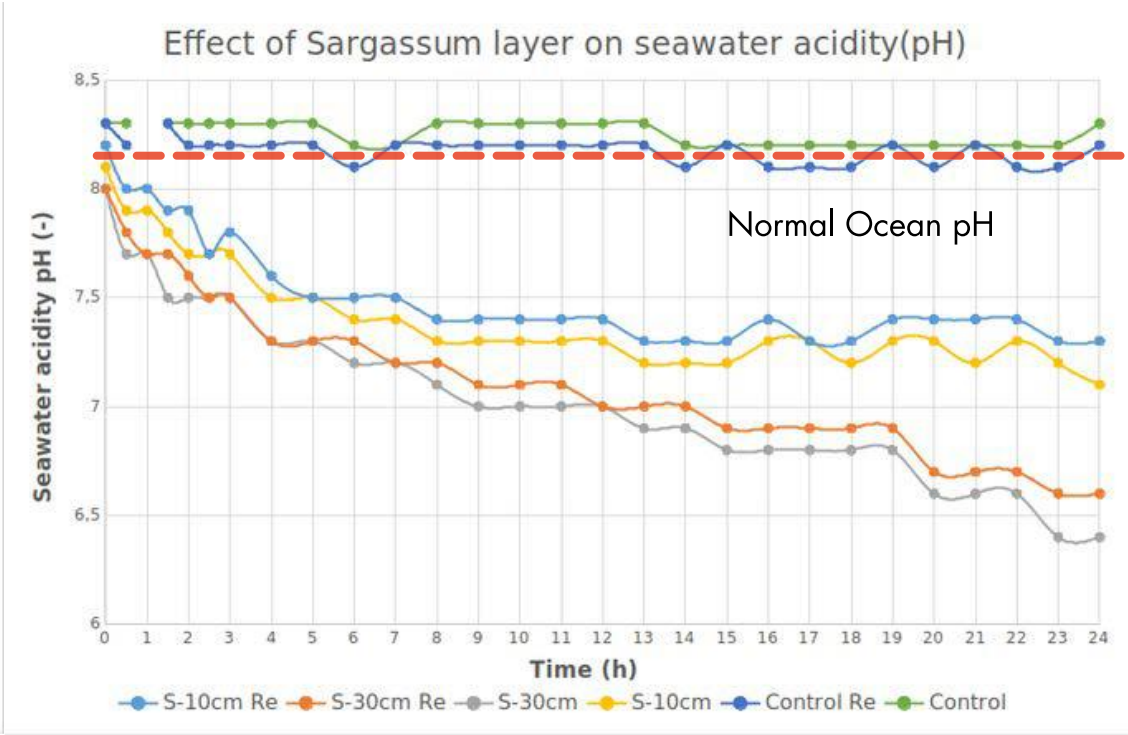
When Sargassum inundates coastal areas, it forms thick mats of seaweed. Once mats become too thick there isn't enough sunlight for all the Sargassum to produce oxygen by photosynthesis. When this happens plants consume oxygen.

Prolonged periods in oxygen depleted waters results in the degradation of Sargassum, which consumes even more oxygen. This oxygen dissolved in the water is very important for a large proportion of marine flora and fauna to breathe. When there is too little this is called hypoxia. Values below 2mg/l are considered coastal dead zones (EU, Kai et al 2019).

Also, when CO2 is produced or when certain chemicals are released during decomposition water becomes more acidic and thus pH becomes lower. Life in the sea is very much dependent on a stable pH of around 8, and when values become too low it can cause coral bleaching. To measure effects of Sargassum inundations an experiment was done to simulate beachings.

Sargassum was placed in plastic tanks dug into the beach, subsequently pH and dissolved oxygen (DO) was measured for 24 hours.





Seawater was placed in 18 plastic tanks dug into the beach. The tanks were divided in three groups one with a 10cm layer of live Sargassum (S-10cm), one with 30 cm layer of live Sargassum (S-30cm) and a control group without any Sargassum (Control). The experiment was repeated, and to mimic seawater exchange every hour 250 ml of the water was replenished with fresh seawater: (S-10cm Re, S-30cm Re and Control Re). All samples were taken outside and had access to daylight. Dissolved oxygen (DO) and pH were measured.

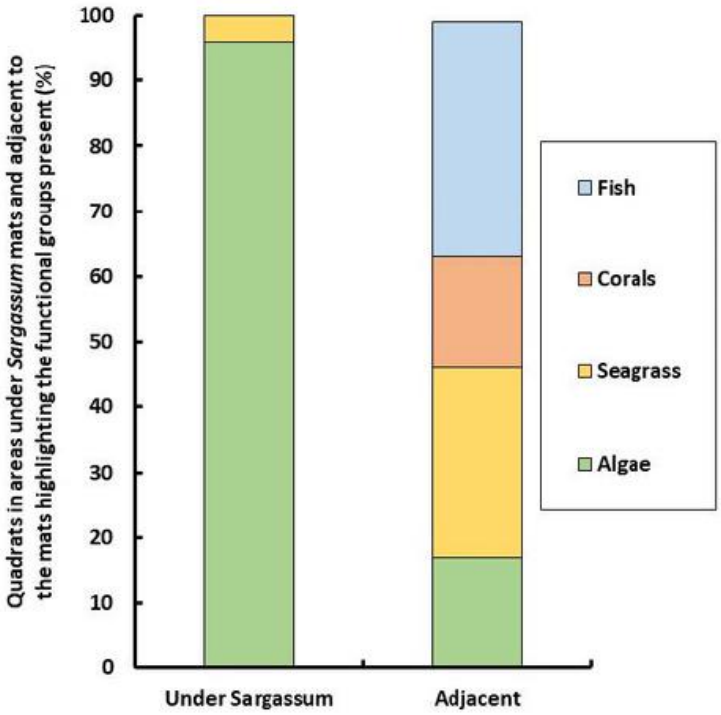
It was found Sargassum quickly consumed oxygen in the tanks causing hypoxia, and within one- or two-hours pH likewise plummeted.

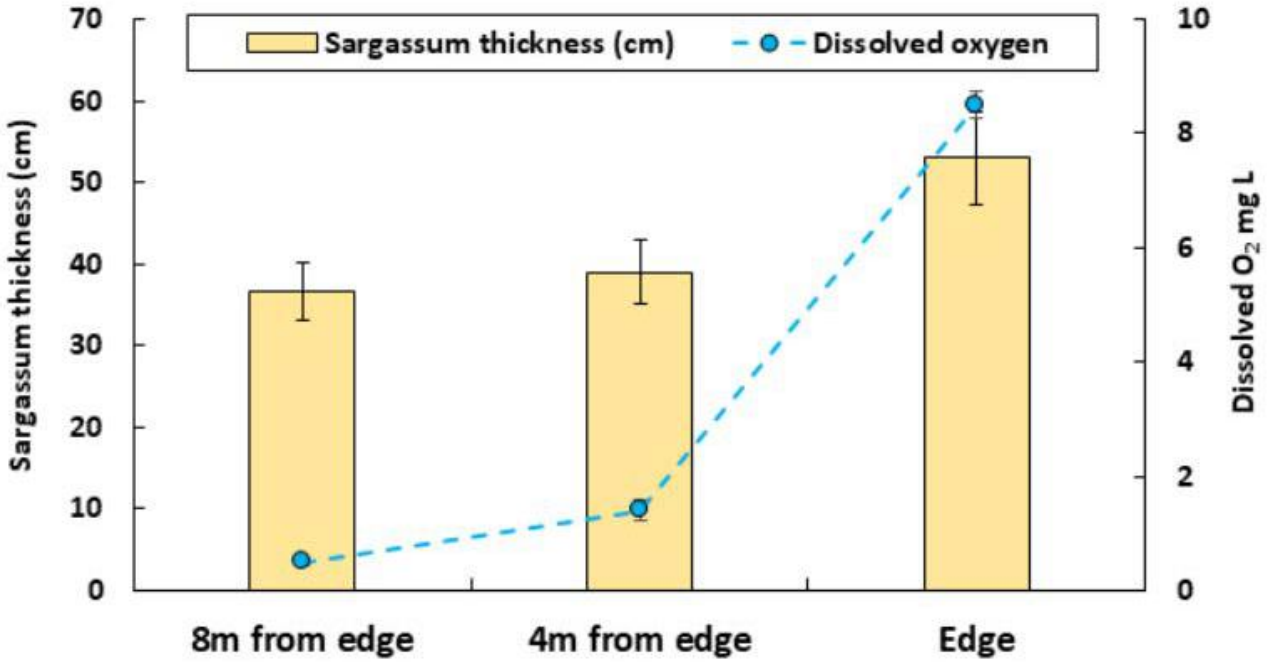
This demonstrates Sargassum has the capability to quickly smother coastal sea life by consuming oxygen and acidifying the water.

SMOTHERING EFFECTS

A research experiment

REVIEW COPY OF END REPORT - NOT FOR PUBLICATION





Smothering Sargassum affects benthic structure and seagrass (Hendy et al., 2021, paper in review)

Our project partner Dr. Ian Hendy from Portsmouth University, faculty of Marine Biology, did extensive research in Quintana Roo, Mexico. The research performed confirms our findings from the experiment held at Sint Maarten.

From the abstract of the research:
Sargassum mats in Mexican bays reduce the biodiversity of nursery habitats. (see graph top left)
In Soliman Bay, Sargassum mats smother the seagrass and under the Sargassum mats light and dissolved oxygen levels were lower.
Anoxic conditions were found: 0.5mg/L for oxygen levels and a 73 % decrease in light.
Water temperature was 4.8˚C warmer under the Sargassum mats. The stress caused by Sargassum mats in Soliman Bay caused a**seven-fold decrease in productivity** of Seagrass (*Thalassia testudinum*) compared to other sites.
Functional diversity was also reduced with lower biomass and an altered species distribution.

"To improve these ecosystems, conservation management and protection must be priority for future ecosystem health and biodiversity."

RECENT RESEARCH ON SMOTHERING

Most recent impact research



SARGASSUM CLEANUP

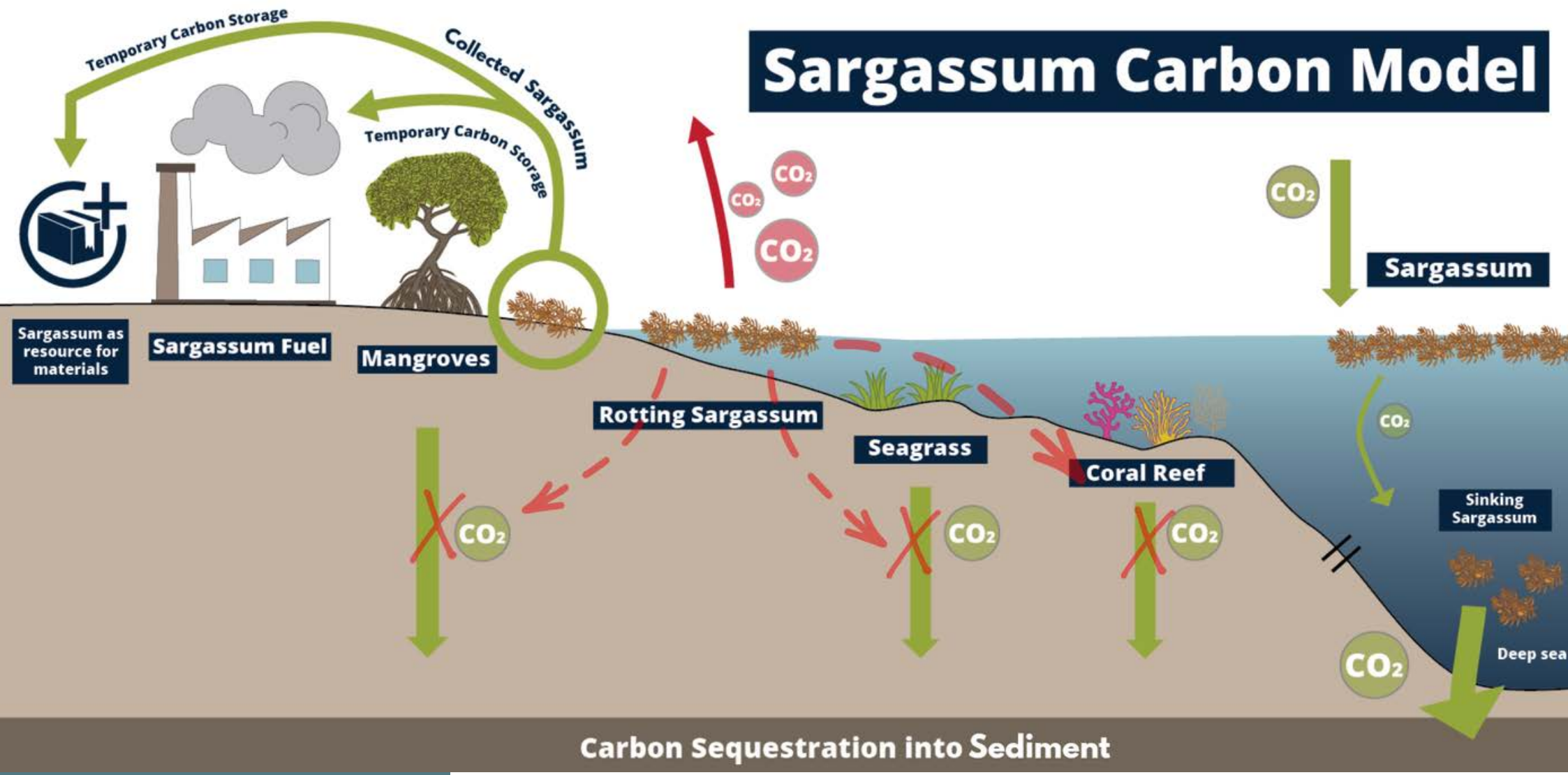
CARBON FRAMEWORK

Different Carbon routes

Sargassum captures sunlight to convert CO2 into biomass. This biomass is a temporary carbon store. The fate of that biomass is important in determining whether sequestered carbon will stay locked, or whether it will get back into the atmosphere.

A number of different carbon routes exist:

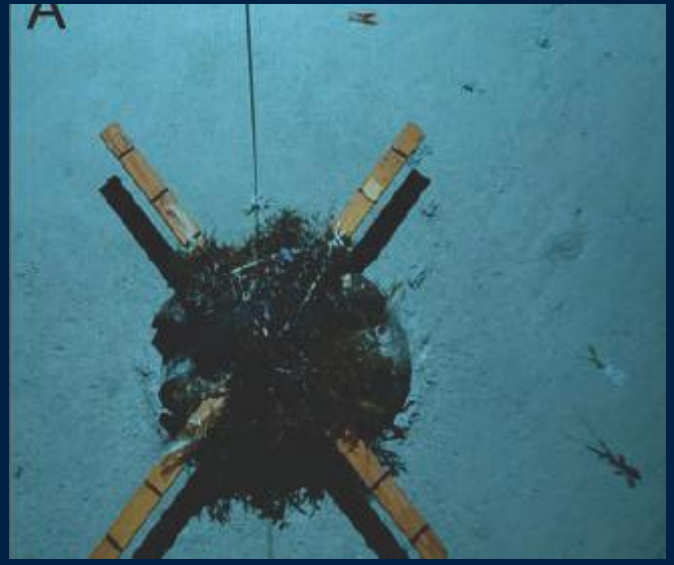
- When Sargassum biomass is broken down in nature CO2 is released.
- When Sargassum biomass is used as a biofuel only CO2 is produced, and the energy used is renewable and replaces the need for fossil fuels.
- When Sargassum is used for materials the sequestered carbon is stored for the duration of the life cycle of the product, and at the same time might prevent use of less renewable resources.
- When Sargassum is incorporated into sediments long term storage of Sargassum can be achieved, either by addition into soils (compost, biochar or dune fortification) or in marine sediment. Maximum storage potential is expected by sinking to deep marine sediments.



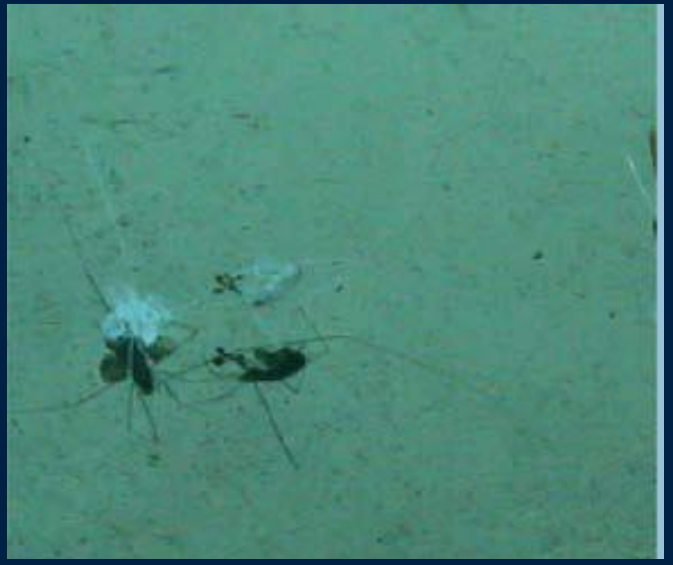
SARGASSUM CLEANUP

SARGASSUM CARBON MODEL

When Sargassum rots away on the beaches, not only will it release the carbon that was sequestered during growth it also negatively impacts coastal ecosystems. Mangroves, seagrass and coral reefs are ecosystems that are highly productive and sequester and store a lot of carbon**Sargassum inundations prevent sequestration by these coastal ecosystems (indicated in red arrows) and might even turn these systems into net emitters of carbon dioxide.** This emphasizes the need for protecting and cleaning up beaches, not only for tourism but more importantly for climate change mitigation. When Sargassum is prevented from beaching, and collected then it can be stored temporarily, e.g. used as fuel (until burned) preventing emissions from fossil fuels, or stored longer when used in materials (with an end of product life cycle). However, when Sargassum is sunk and incorporated into deep sea sediments it can be stored for thousands of years or longer, thus providing an almost permanent carbon storage.

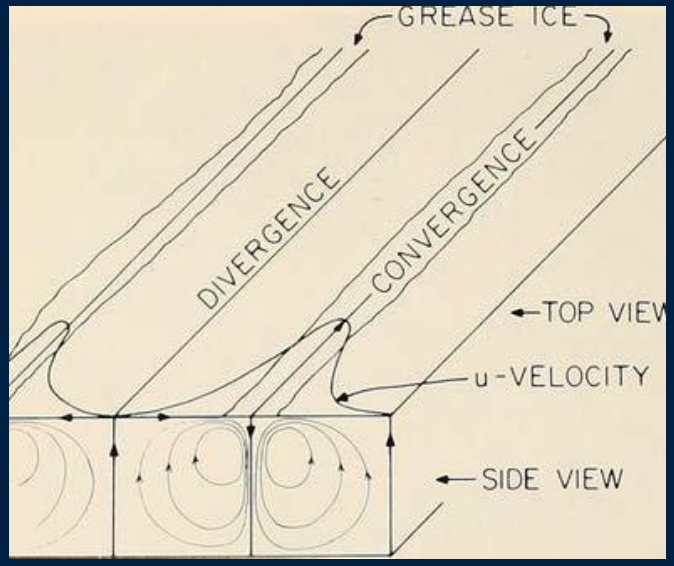






SINKING SARGASSUM

NATURAL PROCESS, EFFECTS, AND ARE WE ALLOWED?







Abstract: *Sargassum* has been photographed on the sea floor at depths of 5000 m. *Sargassum* was subjected to various pressures to simulate the effect of it being carried down in Langmuir circulation. The time-depth relation for *Sargassum* to become negatively buoyant was measured; the plant can become negatively buoyant at pressures of only 30 db if left at this pressure for ≈ 5 h. Both the higher critical pressure for the failure of gas vesicles and the longer resistance to subcritical pressure of pelagic *Sargassum*, compared with the benthonic varieties, suggest an evolutionary adaptation to an open ocean existence. Once negatively buoyant, *Sargassum* will sink to the sea floor in about 40 h. The measurements are consistent with large scale sinking of *Sargassum* given the conditions of strong winds and a deep mixed layer both of which exist in winter months in the Sargasso Sea.

Source: Johnson, David L., and Philip L. Richardson. 1977. "On the Wind-Induced Sinking of Sargassum." Journal of Experimental Marine Biology and Ecology 28 (3): 255–67. https://doi.org/10.1016/0022-0981(77)90095-8.

The sinking of Sargassum has been investigated in the Sargasso Sea where Sargassum occurs naturally. Actually, already long before Sargassum seaweed became invasive in the Caribbean Sea, Gulf of Mexico.

In one study photos of the seafloor showed sargassum in 22% of pictures in the Sargasso Sea which indicates sunk sargassum biomass is widespread. Studies further showed Sargassum seaweeds on the ocean floor are eaten by various animals including: Amphipods (crustaceans), ophiuroids (brittle stars), isopods and polychaeta (bristle worms). This shows sinking of Sargassum biomass occurs naturally on a large scale in the Sargasso Sea and that this seaweed is a food source for abyssopelagic (> 3000m deep) communities.

Pictures of the sea floor also show Sargassum reaches the bottom in its natural brownish colour. This means Sargassum is still fresh and chlorophyll cells are still intact confirming fast sinking.

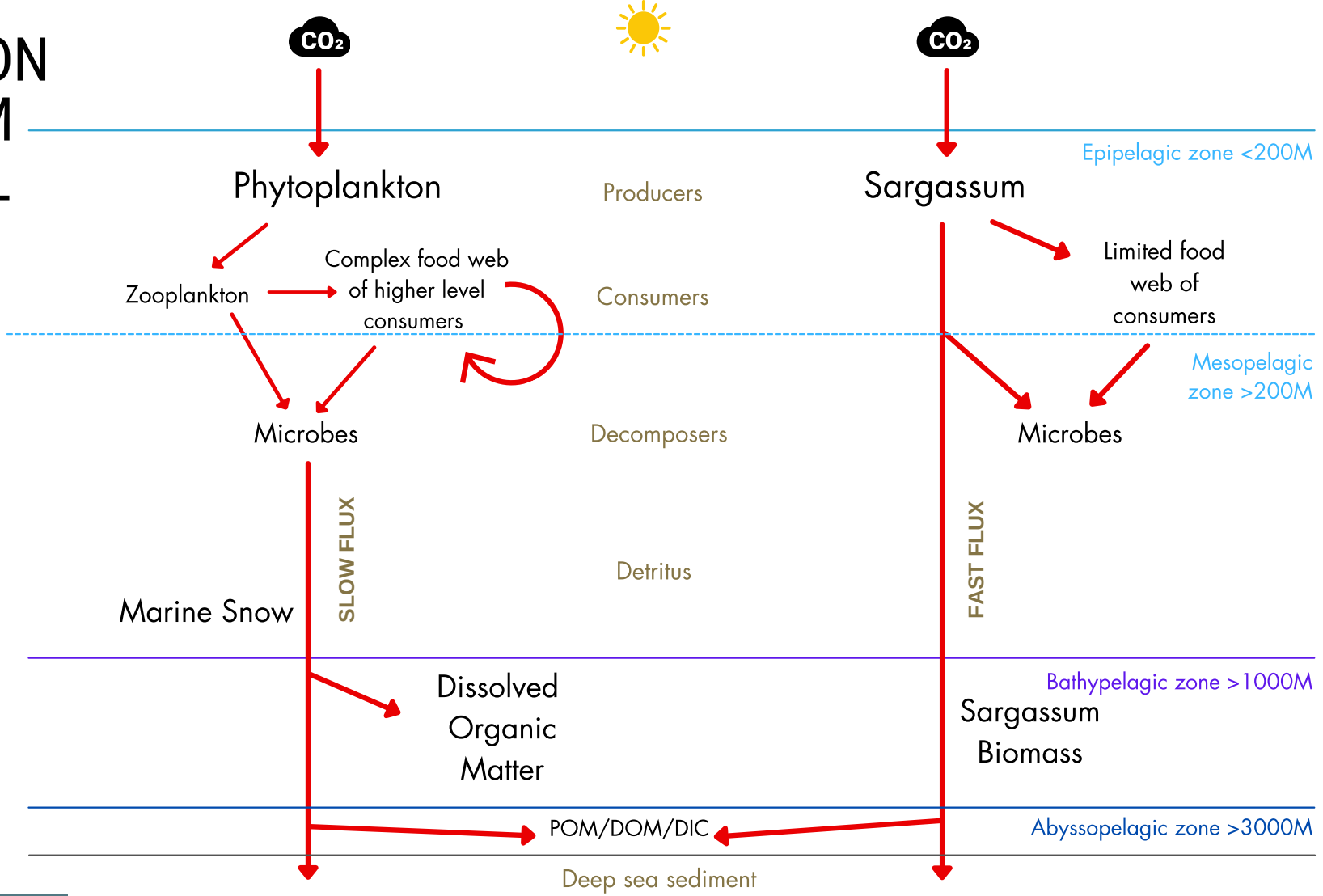
Until now Sargassum sequestration by biomass sinking to ocean floor has most likely been underestimated, a study showed the Sargassum biomass on the ocean floor is several times the weight when in comparison to the surface Sargassum biomass. (Baker et al. 2018) (up to 3,75 g/m2)

NATURAL SINKING PROCESS

What is already known

PHYTOPLANKTON VS SARGASSUM CARBON MODEL

Anthropogenic enhancement of ocean carbon sequestration has been proposed as a geoengineering solution to counter climate change. Carbon will be stored for very long time to almost indefinite periods in the deep-water columns as Dissolved Inorganic Carbon (DIC), (Refractory) Dissolved Organic Carbon (R)DOC) or Particulate Organic Matter (POM) or as sediment in the ocean floor. Macro algae, with Sargassum in particular, consists of large, tough biomass. As of yet there is only a limited understanding of ecological interactions of Sargassum within the oceans food web.



SARGASSUM CLEANUP

SLOW FLUX FAST FLUX

Different Carbon routes

SLOW FLUX - Phytoplankton form the basis of an extraordinarily complex intertwined oceans food web; an energy pyramid which is top heavy (i.e. most biomass is found in higher consumers rather than in the producers). In addition, carbon from phytoplankton sinks down slowly through multiple processes, with incredibly complex interactions, to the eventual deep sea carbon stores. The majority of carbon transport to the deep is through very small particulate or dissolved matter. This**marine snow sinks slowly at a rate of between 13-260m a day** (Laurenceau-Cornec et al. 2015). Thus can be identified as "SLOW FLUX".
FAST FLUX - The current view is that few animals eat sargassum biomass and, in comparison to phytoplankton, it doesn't form the basis of such large food web.**When Sargassum dies it sinks rapidly to the ocean floor, in abt. 40hrs**, i.e. "FAST FLUX". Few benthic consumers eat it and most of it ends up in ocean sediments. The biomass also contains a fairly large amount of the more stable calcite (est. 5%).



EUTROPHICATION & HYPOXIA

DO WE CAUSE EUTROPHICATION AND RISK CREATING HYPOXIC ZONES?

We do not think that deep sea sinking of huge amounts of Sargassum biomass will be problematic in terms of eutrophication and/or creating hypoxic zones.

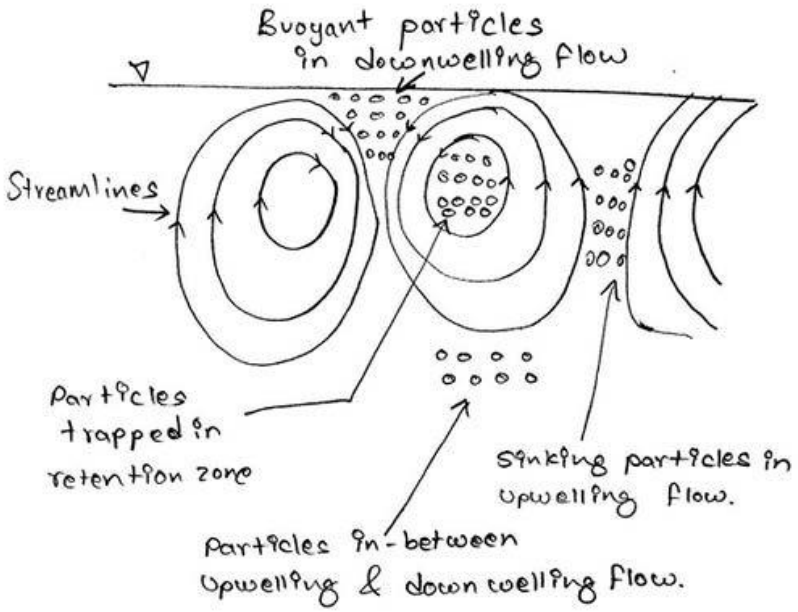
The huge Sargassum blooms are likely formed by excess nutrient run-off of sources like the Amazon river or by other nutrient sources like Sahara sand or deep sea upwellings. When Sargassum biomass is broken down in the deep sea it will release those nutrients. Although nutrients are a limiting factor in the photic zone, the deep sea is a naturally nutrient rich environment. Thus, having a huge influx of nutrients into the deep sea isnot expected to influence deep sea ecosystems.

Another envisioned issue could be hypoxic zones (also called dead zones). Huge algae blooms are observed in area's with surface eutrophication which later result in dead zones devoid of marine life. Because of the influx of huge amounts of nutrients in the photic zone algae can grow prolifically, when these algae die off the biological break down of these algae by bacteria will consume most of the oxygen in that environment. This will create hypoxic zones which most life cannot endure. However, this happens mostly when small algae with a high surface area grow densely in one area.
Because of its small size algae typically can be broken down fast by bacteria and as a result most oxygen is consumed.
As a macro seaweed Sargassum is big, and is chemically and mechanically more difficult to break down by microorganisms alone. Research on the bottom of the Sargasso Sea show it is an oxygen rich zone, where Sargassum seaweed is broken down by bioturbation (by the action of various animals).

Source: *Fleury, A. G., & Drazen, J. C. (2013). Abyssal Scavenging Communities attracted to Sargassum and fish in the Sargasso Sea. Deep Sea Research Part I: Oceanographic Research Papers, 72, 141–147.*

Sargassum takes only about 40 hours to sink to the bottom and studies show it reaches the ocean floor with chlorophyll intact. This mean Sargassum spends little time and is not decomposing at a high rate in the pelagic and mesopelagic zones. Therefore, it is unlikely sinking Sargassum leads to hypoxic conditions.





Langmuir circulation - drawing by Sanjib Gurung

Langmuir circulation is a pattern of sea water circulation that is induced by wind. The vortices created will drag down certain floating particles and can even keep them there for a while. These Langmuir circulation patterns describe why Sargassum usually occurs in long windrows, but is also causing some of the Sargassum to sink.
When Sargassum is 'drowned' long enough at a certain depth, water pressure will cause the sinking process to start.

LANGMUIR CIRCULATION

Forming these lines of Sargassum



SARGASSUM CLEANUP

ENCRUSTATION PROMOTION

Stimulating the sinking process

Sargassum encrusting is part of the natural life cycle of Sargassum in the Sargasso Sea and causes pelagic Sargassum to sink to the deep sea. This happens when sessile organisms get a foothold on Sargassum and cause the air bladders to deflate or when organisms have a higher density (usually due to calcium carbonate structures) and drag Sargassum into the deep.
Are we able to promote conditions for encrusting in order to sink off Sargassum at those locations with depths of over 3-4 thousand meters?
In such areas we might funnel Sargassum mats by making use of wind and ocean currents. At these locations Sargassum mats can be “seeded” with encrusting organisms and/or conditions can be created to promote growth of encrusting species.
In this way we try to mimic the natural sinking conditions present in the Sargasso Sea habitat which exhibits a high level carbon sequestration. With this approach, we will likely have a better separation of bycatch than with mechanical harvesting methods, and we likely need less costly infrastructure and manpower in order to prevent large scale inundations.

Marine Scientific Research related to Marine Geoengineering

7 Potential marine geoengineering techniques may require specific marine scientific research in order to, inter alia:

- better understand the natural processes which will be affected;
- understand their potential impacts on the marine environment;
- understand their potential efficacy for geoengineering purposes; and
- be able to effectively apply the assessment framework(s) to proposals for marine geoengineering

Combating climate change by sinking large amounts of biomass in the ocean can be regarded as geoengineering and will therefore facelegal aspects.

The international treaty "London Protocol" puts limitations on marine geoengineering activities. This treaty was launched in 1972 as: “Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter” as a means to stop the large-scale dumping of all kinds of industrial, chemical and nuclear waste. Since then, the treaty has been updated.

While currently the treaty is not in full effect it might well come into effect in the near future. Also, countries that have signed already are likely to act in line with this protocol. Among these countries are The Netherlands, France and the United Kingdom, all with territories in the Caribbean.

While the London protocol can be seen as a legal limitation, we deeply share the vision behind this protocol, in that we do not want to cause any large scale ecosystem damage.

Therefore, scientific research needs to be done on the ecological effects of large-scale sinking of Sargassum biomass into the deep sea, as well establishing best practices to minimize potential damage to the environment.

LONDON PROTOCOL ON GEO-ENGINEERING

Legal aspects





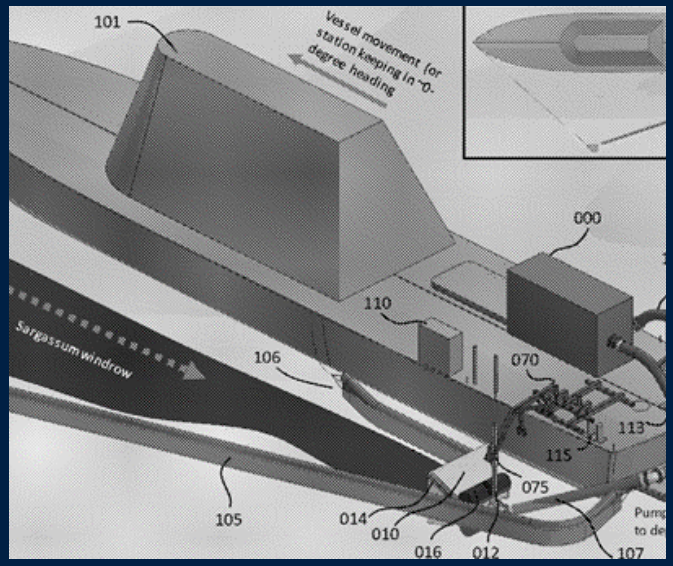


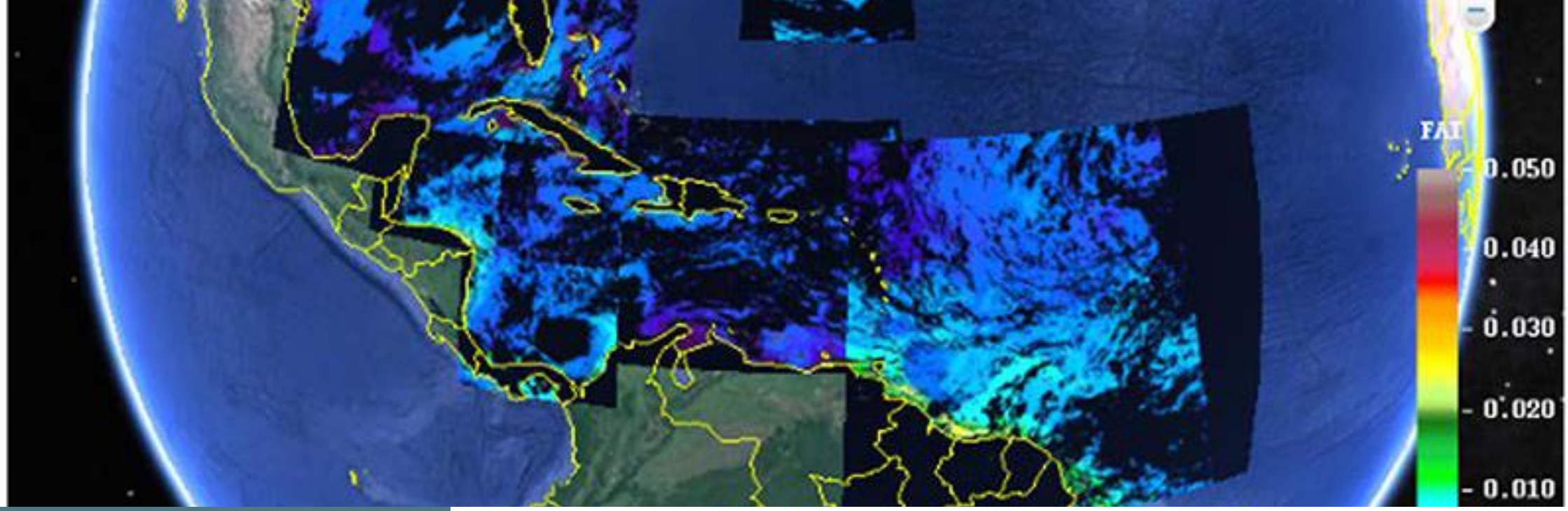
MARINE TECHNOLOGICAL SOLUTIONS

CONSIDERATIONS, SYSTEMS, APPROACHES









SARGASSUM CLEANUP

A SENSE OF SCALE

How much is there, and where

Cleaning up 20 megatons of Sargassum, and using this for prevention of associated beaching problems, using it as a resource for products, or sinking to sequester CO2 sounds appealing to many parties, however this is often far from realistic... specifically if trying to do this offshore.

The scale of the total area involved is gigantic and relative to that the amount of biomass is relatively small. Even in the record year of 2018, involving around 20 Mt of Sargassum measured, this volume was spread over an area of over 8000 km2 and distributed over a length of more than 8000km, 1000km wide.

To get a sense of scale: this is an area of seaweed comparable to two times the size of a country like Luxembourg spread out over the entirety of a country the size of Brazil. This makes actual coverage only about 0.075% of the total, making up for a very wide and dispersed distribution....

When taking fuel consumption of collecting and transporting vessels into account one should cast serious doubts as to whether large scale offshore collection is a sensible thing to do.
Adding to that the challenge of building big infrastructure to collect large amounts of biomass in the wide-open Atlantic Ocean should not be taken lightly.

Taking ecological impacts into account we do see nearshore collection as the most viable option.



SARGASSUM CLEANUP

COLLECTING SARGASSUM

Different types of approaches

Along the different Caribbean islands, and the Eastern coastline of Mexico, experiments have been carried out to find methods to properly collect and process Sargassum.

In order to predict the amounts of Sargassum entering the coastal zone, satellite systems are a useful or even essential tool. Such systems can aid in predictive monitoring to deal with extreme seasonal variability.

To give an example: While there tends to be a growing mass of Sargassum reaching and beaching along the coast of the island of Bonaire in the last decade, the year 2020 showed only little to no Sargassum.

Collecting Sargassum can be done in several ways and on various locations. Broadly speaking, a distinction should be made between collecting Sargassum at sea, off-shore or near-shore, and on-shore.







In many places Sargassum is removed from the beaches manually with rakes and wheelbarrows, or with the aid of surfers who collect Sargassum on surfboards along the shoreline and then bring it to the beach. Apart from being hard work, the associated emissions of decaying seaweed, for example H2S, when collecting can seriously affect the health of the workers, as maximum safe concentrations are often exceeded. These safe concentrations are determined using the Occupational Exposure Standard - OES-limits. (Costigan, 2003)

Industrial machines such as bulldozers, tractors, cranes and heavy trucks are deployed in many locations. This type of equipment has a negative impact on the beach ecosystem, through sand erosion and damage due to soil compacting. It can also have a direct impact on fauna, in particular on sea turtle nesting and eggs.
By then, when clearing from beaches, most ecological damage has already been done at this stage, as well as had its negative impact on tourism.

In general, it can be said that Sargassum collected on beaches is virtually useless as for use in derivative products, because of already partial decay, and because of the mixing with sand and other materials on the beach.

BEACH COLLECTION

Contain and collect







SARGASSUM CLEANUP

OFFSHORE OR NEARSHORE COLLECTION

The best place to harvest

Since onshore collection has a serious impact on the beach ecosystems and has serious erosion effects, collection at sea is the preferred option. This can be done nearshore or further away. When collecting far offshore, the enormous size of the area set against relatively little biomass makes this option less realistic economically. Another essential element is the fact that offshore Sargassum can host large amounts of species, as explained in the report published by DCNA (2019).

Since offshore collection will implicate high costs for equipment, and infrastructure, and energy use, near shore will be the best method in most situations. Thus, we believe focus should be on near shore collection. This is in line with recommendations by CERMES (2020) stating: Where possible, it is generally agreed that in-water collection very close to shore is often preferable to beach collection, where permitted. This approach avoids removal of sand and damage to coastal vegetation.

For collection nearshore, the first question that needs to be answered is: what is the ideal location? Local situations may differ considerably, i.e. the windward or leeward side of the island.

Next the type of equipment should be selected with care. Numerous technologies, methods, and types of equipment have been developed or are on the drawing board:

- Specialized vessels with conveyor belts, collecting the Sargassum from the sea surface
- Boom technology, either using ‘regular’ oil booms or specifically designed booms for Sargassum
- Multipurpose vessels which are equipped with both collecting and processing machinery
- Equipment to collect and pump Sargassum to the deep-sea

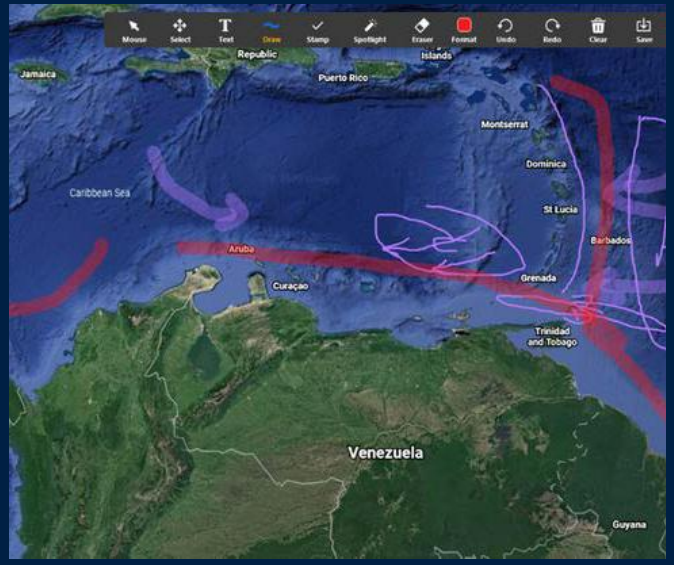


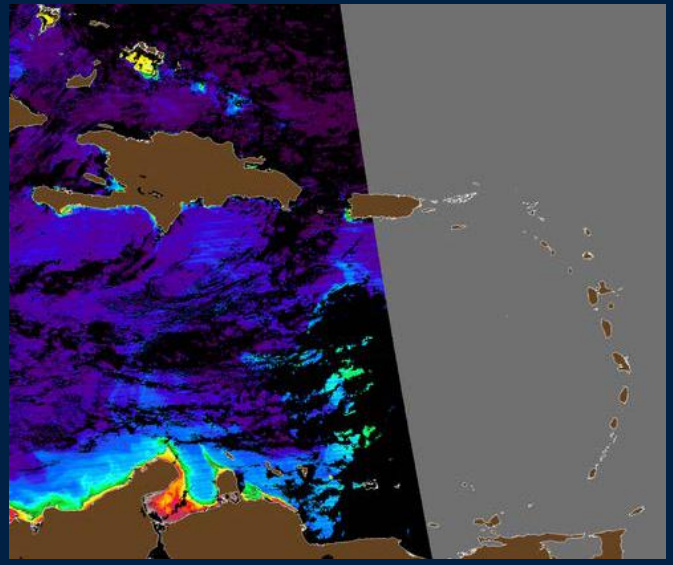
SARGASSUM CLEANUP

INSIGHTS ON COLLECTING

What is the best approach

- In view of the environmental aspects of harvesting, the biggest challenge lies in preventing damage to coastal ecosystems, health, communities and their economies.
- Many marine and coastal fauna are associated with Sargassum and may thus be captured while collecting Sargassum. Although there will always be some collateral damage, such as encrusting species which are attached to Sargassum, bycatch should be avoided, and research to prevent this should be ongoing.
- Nearshore collection, with simple and sturdy infrastructure using booms and collecting equipment is the preferred option.
- It is also advised to use available vessels operated by local communities. To test this further, pilot projects are needed to define the perfect configuration of boom placement and collection equipment.
- It is essential to prevent collected Sargassum from lingering and sinking near shore, causing eutrophication and other negative effects of smothering. This can be avoided by timely collection.

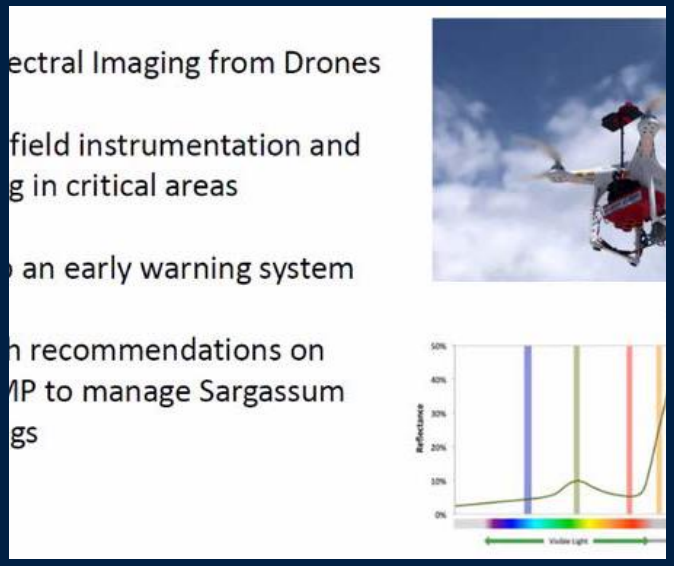


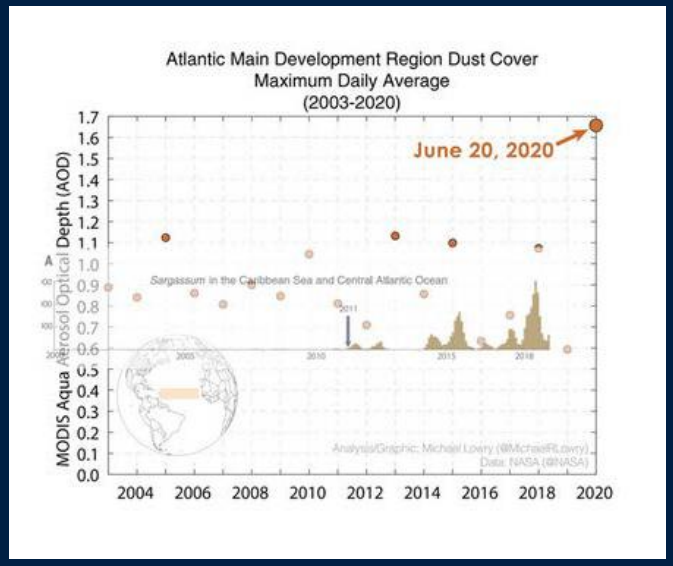


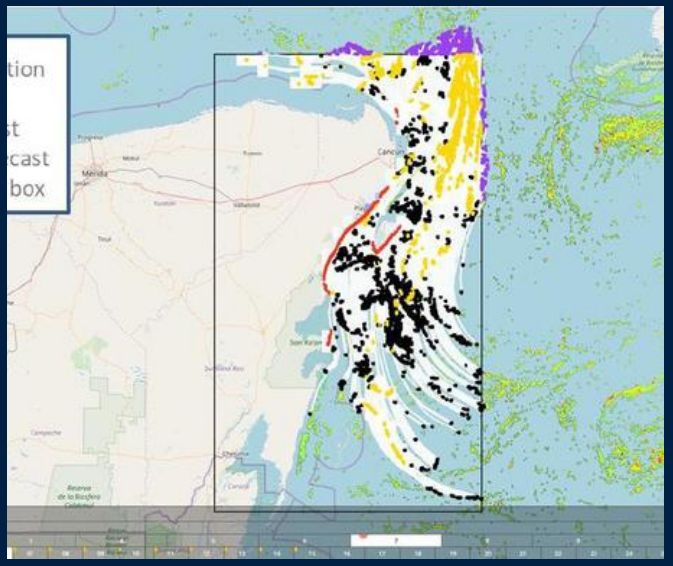


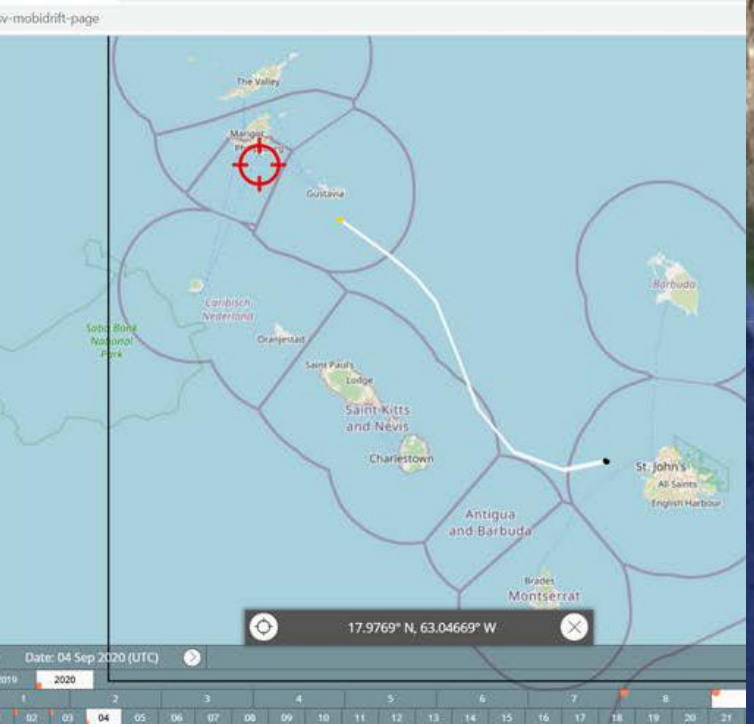
SATELLITE DATA AND MONITORING

MONITORING - FORECASTING - ANALYSIS











In order to determine whether Sargassum is bound to wash ashore, and causing coastal areas to be inundated it is important to be able to forecast and monitor Sargassum windrows and matts. Forecasts and Monitoring show when and where the Sargassum seaweed will become a problem, by determining how much Sargassum is present, its trajectory, if and when it is likely to beach.

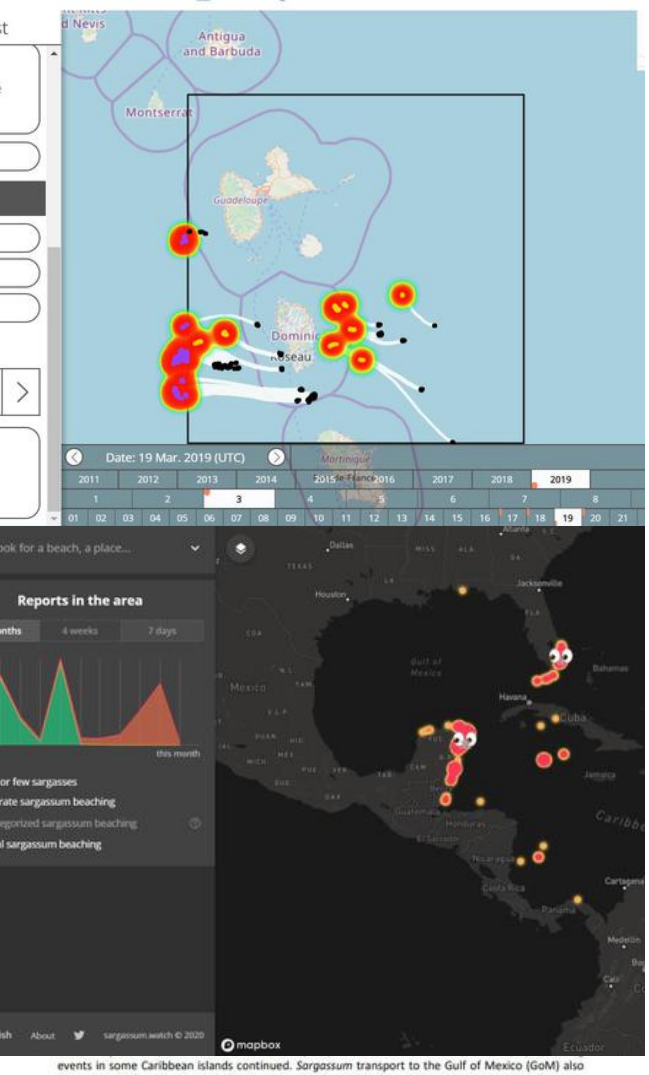
An important consideration would be to start classifications of coastal zones in relation to Sargassum in order to determine priority and decide on a protection, mitigation or a laissez-faire approach.

A number of services have already been developed. iMara (https://imara.earth/), a Dutch startup established in 2020 to use geodata for visualising environmental impact, performed a study at the request of Climate Cleanup to specifically look into the availability and use of monitoring and satellite services.
The next page provides an overview of the findings.

IMARA

MONITORING SERVICES

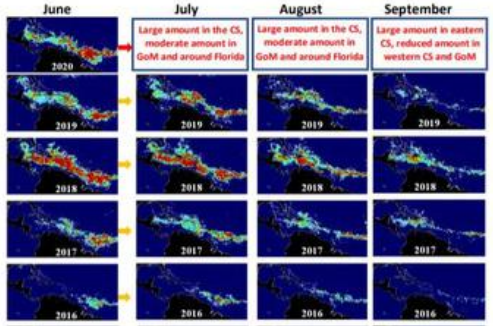
Data and forecasting



events in some Caribbean islands continued. *Sargassum* transport to the Gulf of Mexico (GoM) also increased, with moderate amounts found in the Florida Straits and along the east coast of Florida. Miami Beach started to see some inundation. In all regions combined, the total *Sargassum* amount increased from 8.7 M tons in May to 12.7 million metric tons in June, lower than June 2018 (20.4 M tons) but higher than June 2015 (9.9M tons) and June 2019 (9.5M tons).

Looking ahead, the eastern Caribbean will continue experiencing large amounts of *Sargassum* in July to September 2020 with many beaching events. The western Caribbean will also experience moderate amounts. The situation is expected to be similar to summer 2015 and 2019, but with larger *Sargassum* amounts. In July – August, more *Sargassum* will reach the eastern GOM, enter the Florida Straits, and transport to the east coast of Florida. The bloom may start to decrease from late August to September.

More updates will be provided by the end of July 2020, and more information and imagery can be found from the *Sargassum* Watch System (SaWS, https://optics.marine.usf.edu/projects/saws.html)



SATELLITE & MONITORING SERVICES

SAMtool – CLS (datastore.cls.fr/samtool) would offer a good service in which most data is already processed and the requested information is available in a web platform. The service gives a daily overview of collected data and information about the presence of Sargassum. The service uses optical data (the sensors cannot take measurements in the presence of cloud cover) and does not have correct data on cloudy days. When necessary CLS experts will manually process radar data.

Optical Oceanography Laboratory (optics.marine.usf.edu/) seems very promising with high data availability and useful information. The data is free to use, but it requires a data specialist / professional to use and process the data into suitable and actionable information. Whether hiring a data specialist is worth the costs, depends on how often data is needed, used and the available budget.

Sargassum Watch (sargassumhub.org/monitoring/) might be very interesting to use during internships. It is a tool that collects information from the field and stores this over time on an online webservice. This means that collected information (such as photos or videos) by interns can be shared via this portal. Not a necessity, but sometimes a picture is worth a 1000 words: it can be an interactive, visualisation of the situation on the ground during the internships.

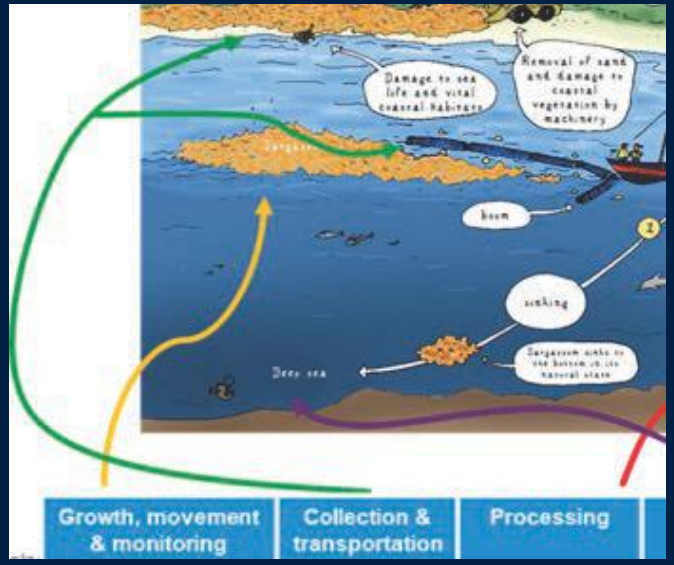
Sargassum monitoring service (sargassummonitoring.com) will give an insight via images on the potential project areas and it will show where most data is collected. Valuable information in order to plan activities, and to see which stakeholders are actively involved / suffering from the beaching of Sargassum. When there is a focus on a small area, such as Bonaire, the use of a small-scale service can lead to high user involvement. Partners, inhabitants or tourists could use their mobile device to create data for a service that shows where Sargassum beaching areas are.

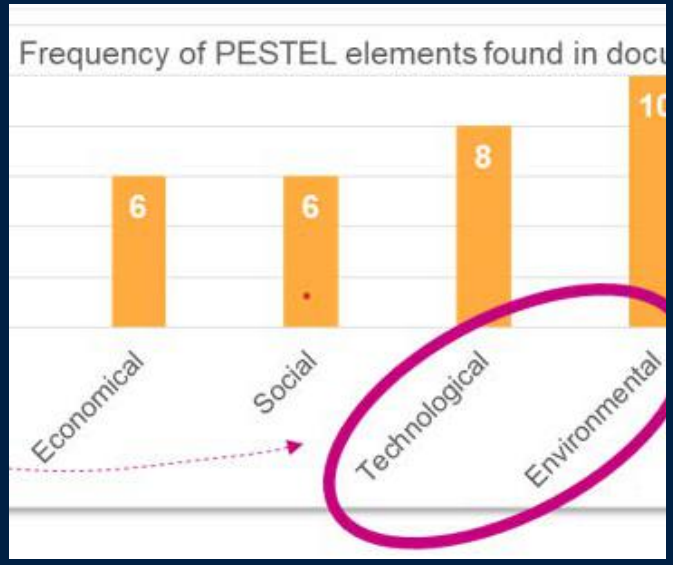
With the use of a small-scale service, there will be more user involvement. However, this is not sufficient for large areas with fragmented stakeholders: a dedicated group of users need a dedicated organisation. Otherwise it will be very hard to create a well-used service.

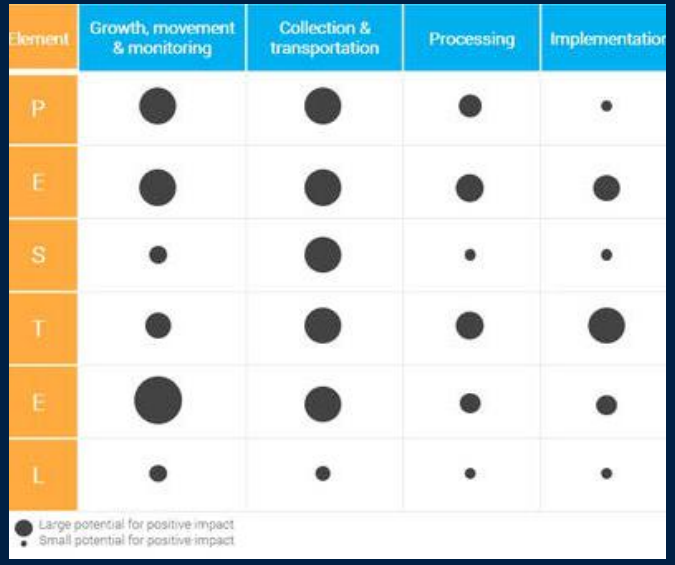
A large focus area in combination with daily processing of remotely sensed imagery into information about Sargassum, asks for a large infrastructure. CLS and the Optical Oceanography Laboratory have both such an infrastructure in place and the manpower to maintain services and keep them up to date.

From iMara - In conclusion: if the project area is small, a consideration is to create a new service which is completely suitable to the data needs that the direct users of the data have.

However, if the project area is large, the advise is to use an existing service with an underlying strong data-storing, data-processing and data-visualisation infrastructure in place.







RISKS & OPPORTUNITIES ASSESSMENT

PESTEL ANALYSIS BY KPMG AS COMMISSIONED BY CLIMATE CLEANUP

Factor	Example
Political	Local and (inte
Economic	Tourism, fishe
Social	Health, NGOs
Technological	Innovation, R&
Environmental	(Marine) ecolo
Legal	Local and (inte

TOP 5	Growth, movement & monitoring	Collection & transportation	Processing	Implementation
1	Negative impact on ecosystems	High costs for large quantity collection	Lack of recognition by governments of the potential benefits withholds development	Additional carbon sequestration
2	Negative impact on tourism and fisheries	Close to shore collection decreases negative impact	Relatively low yield from anaerobic digestion	To be used as a variety of end-products
3	Potential for variety in local economics	Lack of guiding policies	Sargassum processing knowledge stimulates local innovation	No continuity in supply
4	Insufficient regional sharing	Public-private partnerships proven to be advantageous	Many processing techniques in early or pilot stage	To be used for shore ecosystem fertilization
5	Some legal basis for action	Potential role for local fisheries		

Red: Risks associated with the Sargassum Cleanup project
Green: Opportunities

Collection & transportation	
Opportunities	Risks
Local, regional and national partnerships help managing and mitigating impact Public-private partnerships have proven to be advantageous in managing impact	• Lack of guiding policy by (local) governments on (preferred) methods c collection and issuance of harvesting permits
Insurance companies in French Antilles cover losses caused by Sargassum	• Large quantities to be removed quickly before formation of smelly gases; this very costly
Community building by organizing beach cleanups Local fishermen / dive + surf clubs could play a role	• Potential health impact on people due release of toxic gases during cleanup • Manual cleaning: many people
Using booms reduces impact on beaches Special (small) ships with conveyor bels or pumps to collect the Sargassum	• Close to shore collection only in calm waters

Summary and vision: focus on identifying and quantifying long-term impact

Based on the literature review, we have seen that most research is currently focused on the environmental impact of Sargassum and technological solutions to address this. The interviews have pointed out that in terms of the current status of the positive and negative impact of the problem, the main challenges are found in the growth, movement & monitoring and collection & transportation phases.

Our observations



- **Limited discussions on long term financial impacts** of shifts in ecological systems such as mangroves, seagrasses, and coral reefs and smaller-scale social and economical activity (such as local fisheries) caused by Sargassum
- **Limited international cooperation** in addressing the currently faced issues
- Current Sargassum collection and processing efforts in the Caribbean and Gulf of Mexico are mainly driven by **short term financial incentives** such as loss of income from tourism
- Smaller Islands/nations have **little financial and physical capacity** to address these long term and even some short-term impacts
- Most business cases for processing and implementing Sargassum on a larger scale are **in a startup phase**

Our recommendations

1. CC should focus on **engaging in partnerships** to **increase international cooperation**.

2. As incentives to address the problem are mostly financial, an **assessment on the long-term financial impacts** of ecosystem degradation and local economies should be executed to deepen discussions both with (local) governments, companies, tourism industry, NGOs and initiatives as the Caribbean Climate-Smart Accelerator.

3. The **focus** of addressing the issue should lie on the **first and second stages of the value chain**, as visualized on page 10.

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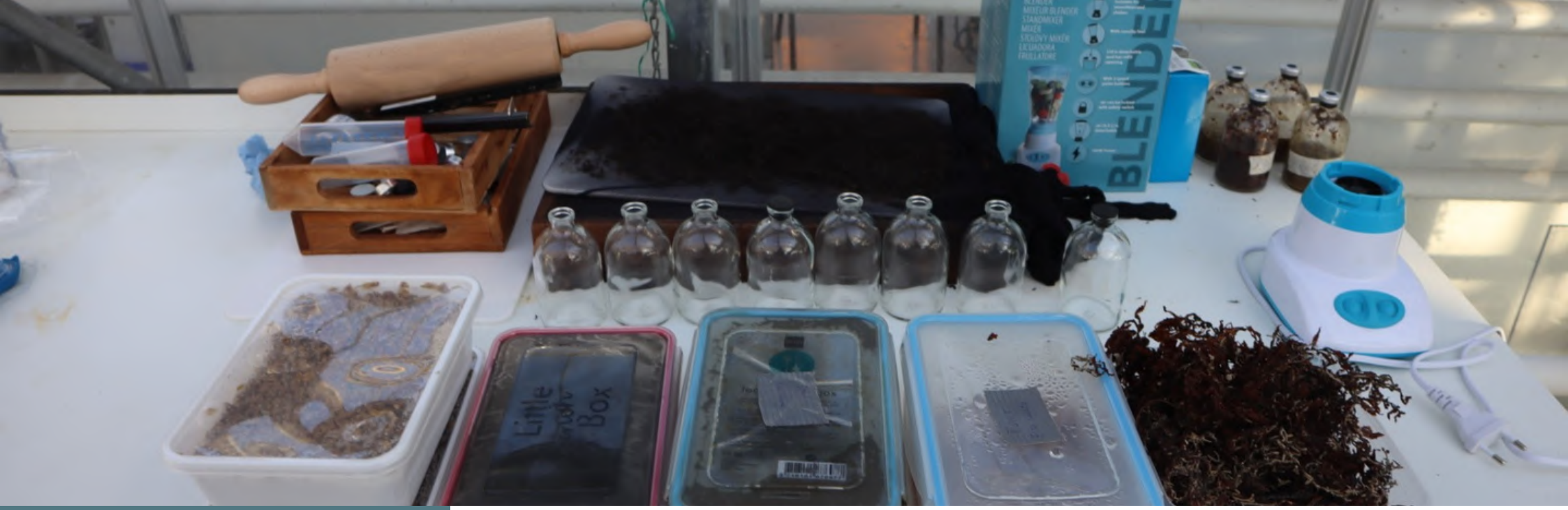
BIOPROCESSING AND VALORISATION

COLLECTING - DRYING - PROCESSING - PRODUCT(S)









SARGASSUM CLEANUP

RESEARCH ON VALORISATION

Fons Janssen's internship

Fons Janssen did an internship for his biotechnologist Master thesis at Wageningen University: *"Bioprocessing of Sargassum natans and fluitans" - December 2020.*

Fons' research contained a literature study at home, a field trip to collect, sample and dry Sargassum in Sint Maarten, as well as lab research at Wageningen AlgaePARC.

In Sint Maarten, Sargassum seaweed was collected, testing collection techniques, and the biology and ecology of the Sargassum was studied. The environmental effects on the beach and bay areas were researched and a stakeholder analysis was performed.

In Wageningen anaerobic digestion and paper production was tested, and samples were sent to TNO to research the potential of Sargassum in Super Critical Water gasification.







THESIS RESEARCH CONCLUSIONS

Multiple start-ups and business are trying to bioprocess the Sargassum for energy, materials or fertilizer. However, only a few articles are currently published on the composition of *Sargassum natans and fluitans* and its usage in anaerobic digestion, and for paper production.

The collected and sundried Sargassum in Sint Maarten in September 2020 contained 22% water, 27% ash, and a C/N ratio of 27. This research experimented with more input configurations for mixed anaerobic digestion of Sargassum, in an attempt to overcome the salt, heavy metal, and polyphenols inhibition on biogas production. Different anaerobic digestions mixes were carried out, with varying cofeeds of spent grains, mango and banana and varying inocula (being anaerobic sludge, fish guts and cow dung). Adding inoculant and cofeed with Sargassum increased gas production, while spent grains with inoculant did not produce much biogas.
The produced gasses mainly consisted of CO2 and H2, while only traces of methane were detected. The low methanogenesis is possibly caused by residual oxygen, high salt concentrations or polyphenols. The NaCl salt concentration varied between 15-40 g/L. These high concentration levels from dried Sargassum would require marine based anaerobic digestion, replacing the scarce fresh water with abundant sea water. The samples still performed acidogenesis producing CO2 and H2 and volatile fatty acids, lowering the pH to 3.5-4.5. The maximum production was only 0.6 ml H2/g volatile solid Sargassum.
The experiments done trying to use dried Sargassum for paper production were not successful. Different bleaching, as well as basic and acidic hydrolysis conditions need to be pursued, as the produced paper crumbled easily and still had a deep brown colour. This indicated Sargassum has a different composition than the green algae Cladophora or the brown seaweed extract Algiflor.

To valorize and bioprocess large volumes of Sargassum in anaerobic digestion, more research is required finding salt-tolerant inoculate so a switch can be made from freshwater to seawater. Also, the difference of fresh Sargassum compared to ensiled or dried Sargassum needs be further studied to create a constant feed-in stream. When processing rates are low, storage is required for the beached influx, which are irregular in time and mass. Finally, more research must be done on dealing with the heavy metals if the digestate is to be used as fertilizer or bio-stimulant.

Fons Janssen, Master Biotechnology, Wageningen University, 2020







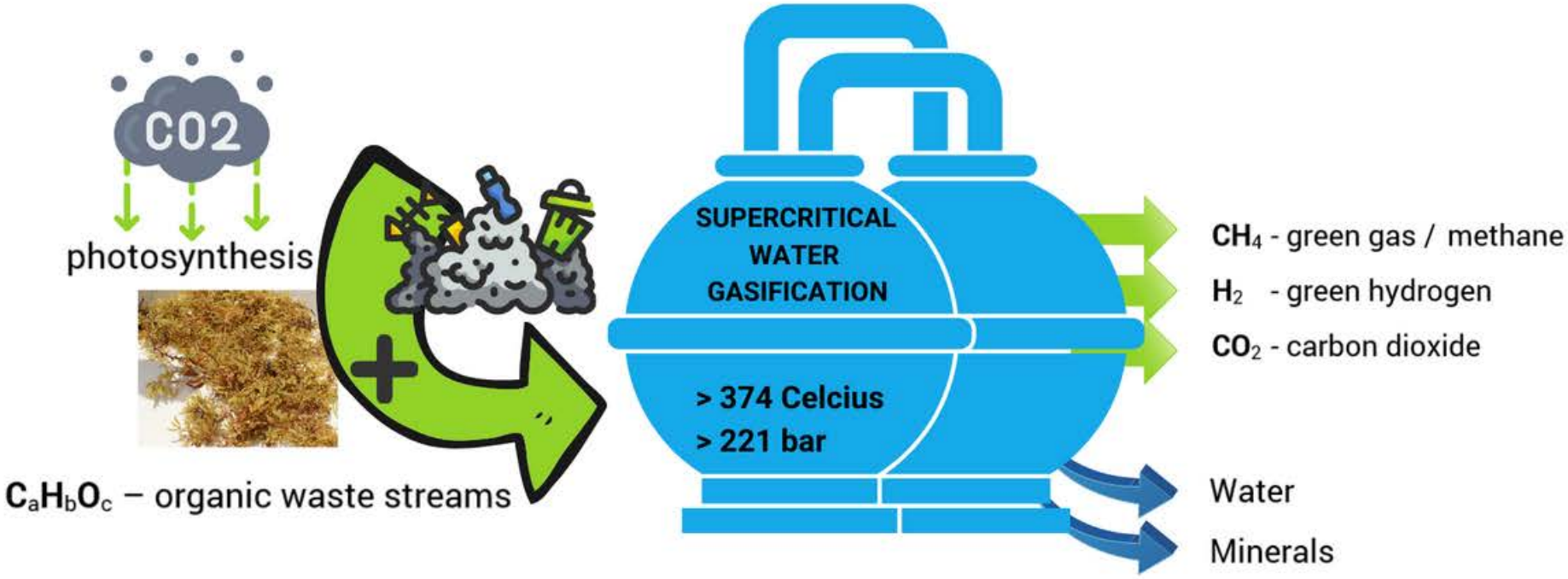
ADDITIONAL REMARKS ON DIGESTION

Our research shows that valorization through anaerobic digestion is not a straightforward path and several serious challenges need to be overcome to turn Sargassum into a commercially viable product. The biggest hurdles to take are the low yields, the high ash and salt content as well as the level of heavy metals contained, such as Arsenic. Low yields might be improved with by finding suitable co-feeds and inoculants. Current solutions usually don't mention how to deal with the huge volume of wet and dry fractions. While the nutrient rich digestate likely can be used as a base for fertilizer product, the high salt and arsenic content in Sargassum needs to be dealt with.

Another thing usually not mentioned is the high salt content which seriously inhibits bacteria found in conventional non-marine inoculants. Testing typically occurs at small scale where the use and amounts of fresh water needed for washing and processing is often overlooked. Any large scale setup will have to use enormous amounts of fresh water already a scarce comoddity in the Caribbean. Most fresh water sources on the Caribbean islands come from energy intensive and costly processes. These are aspects that need to be thought of before scaling up.

One strategy is looking for marine based inoculants (e.g. from fish guts or marine sediments) opening the opportunity of using the plentifully available seawater as process water. An untested solution proposed by N'Yeurt et al. 2012 might offer a potential mechanism for large scale off shore digesting. By using 200m deep submersed digestors one can make use of favorable conditions that allow for direct separation of the CO2 and methane gas. Additionally this makes transport and handling of the biomass easier while fairly simple constructions can be used that do not have to be build on the scarce lands available and would allow easier scaling up. While with merits, this idea is far form being tested and comes with its own challenges with digestate and carbon dioxide dynamics at these depths.

While anearobic digestion of sargassum (and cofeeds) has many challenges new sources of renewable energy are desirable. The Caribbean is known to be very much dependent on imported fossil fuels (87%). The region would greatly benefit from having a more diverse, locally produced and renewable energy market.



The greatest challenges in valorisation of Sargassum biomass is the need for drying the biomass and the high ash/salt concentration. Drying either needs a large amount of energy, or huge areas when drying in the sun. While high salt or ash concentration inhibits anaerobic digestion and pyrolysis processes. **Supercritical Water Gasification (SCW)** is an innovative experimental technology that can better deal with these issues. **Above a temperature of 374°C and a pressure of 221 Bar water becomes 'supercritical', which means there is no phase boundary between gas and liquid.** Under these conditions' biomass and other organic substances like plastics degrade into smaller molecules like hydrogen, methane, and short chain carbohydrates. These output chemicals can form the basis of a modern renewable chemical industry. SCW has the advantage that it can deal with wet biomass. Another advantage is that salts will precipitate from the water and can be separated. This holds potential when being used to recycle for fertilizer compounds. What is unique about this technique is that it isn't specific to a certain type of feed. Anyone familiar with valorisation of biomass knows that most value chains are highly specific to the type of biomass and can't really deal with fluctuations in composition without affecting yields. SCW is not only unspecific for biomass, it can also be combined with input from plastic wastes. As of today many Caribbean islands lack proper waste management which pollutes the islands and coastal ecosystems. Considering Sargassum influx is highly seasonal and can be combined with biomass and (plastic) waste streams, SCW holds great potential when it comes to sustainably, dealing with Sargassum biomass and municipal waste streams while providing new green industries.

SUPERCRITICAL WATER GASIFICATION

An innovative technology option

ResultsTKI-Sargassum elementanalysis WFSR

21-12-20 Samples Climate Clean Up

					Elements in mg/kg (productbasis)				
WFSR number	Date received	Product	Location	Moist (%)	Arsenic (total)	Cadmium	Mercury	Lead	Iodine
200606440	12-11-20	Sargassum	Open sea, Sint Maarten	35,8	71	0,23	<0.015	2,2	77
200606441	12-11-20	Sargassum	Open sea, Sint Maarten	42,4	77	0,2	<0.015	4,2	64
200606442	12-11-20	Sargassum	Wet compost heap Point Blanch bay	82,7	7,3	0,11	<0.015	0,18	24
200606443	12-11-20	Sargassum	Charcoaled Guana bay	58,6	15	0,17	<0.015	0,25	58

				Element content in mg/kg dry matter				
WFSR number	Date received	Product	Location	Arsenic (total)	Cadmium	Mercury	Lead	Iodine
200606440	12-11-20	Sargassum	Open sea, Sint Maarten	111	0,36	<0.023	3,4	120
200606441	12-11-20	Sargassum	Open sea, Sint Maarten	133	0,35	<0.026	7,3	111
200606442	12-11-20	Sargassum	Wet compost heap Point Blanch bay	42	0,64	<0.087	1,0	139
200606443	12-11-20	Sargassum	Charcoaled Guana bay	36	0,41	<0.036	0,61	140

SARGASSUM CLEANUP

ARSENIC CONTENT

Use in composting?

From the results of the sample testing performed by WFSR (Wageningen Food Safety Research) it is shown that the Sargassum collected in Sint Maarten does contain high levels of toxins. Arsenic content exceeds maximum permissible limits for several countries (including EU, Canada, USA and New Zealand) Without treatment the arsenic content is therefore prohibitive for use as food product for animals and humans, but also prohibitive for compost / fertilizer for food crops. One company has a patented (WO2020/081671 A1) treatment for making a Sargassum based fertilizer/bio-stimulant, through which they claim to have eliminated arsenic from their product.

The high salt content of Sargassum also makes it unsuitable to use as compost for crops. However, arsenic and salt concentrations can be lowered by mixing with other compostable biomass. Another possibility would be to use salt tolerant crops and saline agriculture techniques for material production. Salt tolerant types of bamboo, hemp or Agave sisalana (sisal) could be relevant tropical plants for saline agriculture producing non-edible products. These plants could relieve the soil from heavy metals and salt and in time provide healthy agricultural soils.

Creating large volumes of Sargassum compost could help to restore nature, sequester carbon or improve soils for climate adaptation, but with the caveat of dealing with the levels of toxins and salt it contains.

SARGASSUM USES GUIDE - CERMES - 1







In September 2020 CERMES submitted a "draft working copy submitted to the CC4FISH Project" on the many uses of Sargassum. Since this work is very comprehensive we feel it is important to reference this report. It contains many references and insights to the use and valorisation of Sargassum.
A brief commentary by our team was made on the report and a number of the described uses.
The production of the CERMES report was assisted by the Food and Agriculture Organization of the United Nations (FAO). FAO is acknowledged as the source and copyright owner of the pictures associated with these pages.

- The SCW gasification of Sargassum is not mentioned in the CERMES report. Together with TNO, a Dutch Research and Technology institute we are investigating the use of SCW for processing Sargassum. The SCW technique is different and so is the outflow: producing synthesis gas.
- In the agriculture chapter, the entrepreneurs and researchers look at the production of compost / liquid fertilizer / bio-stimulant for conventional agriculture. Salinisation and heavy metals are indeed problematic but might be dealt with. A partnership with the Saline Farming Foundation could yield new possibilities with Saline farming techniques, using non food crops for bioremediation of heavy metals.
- We think the Texan sea bales very smart to think about strategic "landfill" which is also a carbon sink, and provides coastal protection. Though many areas in the Caribbean lack coastal dunes.
- We got to know of many entrepreneurs with research projects for developing paper, compost, and biogas. This offers opportunities for us to further refine the valorisation experiments these research projects touch upon.
- SOS Carbon seems to be an initiative with which a good partnership could be build in order to further develop the sink process. The entrepreneurs show that they have already run the first demo.
- In some initiatives there are also residual flows (pyrolysis -> salts, liquid fertilizer & anaerobic digestion -> digestate, mulch, paper -> nutrients + heavy metals).
- Some solutions make products but don't fully use the biomass, which might leave problematic waste streams. Most entrepreneurs do not mention how they handle all residual flows responsibly.







SARGASSUM USES GUIDE - CERMES - 2

Based on our own findings our position on many applications has remained largely unchanged:

- Feed: Very limited possibilities due to salt and heavy metals and phenolics. It is much better to grow a specific macro-seaweed or microalgae for this.
- Pyrolysis (including biochar): Burning is often the intuitive first thing to think about when dealing with biomass, however there are several serious challenges to these solutions. First of all, these solutions require drying the biomass, this requires a lot of energy, or a large area when sun drying. On top of this the very high ash/salt (25%) content limits these processes. Furthermore, biomass and especially a sulfur and heavy metal rich one like Sargassum produces very polluting emissions.
- Compost: can be done under specific conditions. Salt and heavy metals must be dealt with by effective agricultural practice. Holds potential to deal with large volumes, and can be done in combination with other waste streams. Provides soil restoration and a carbon sink.
- Mushrooms: We are very skeptical that the mushrooms do not absorb the heavy metals, so doubt the suitability of this.
- Biogas: We need to learn more about how to collect a good halophilic inoculum and which cofeeds we want to use to have the correct C: N: and C: S ratios. Due the lack of available fresh water in the Caribbean we think only sea water based anaerobic digestion is scalable.
- Adobe bricks: This seems a very good basic solution. We are curious why this solution is not being scaled up any further as many of the islands are under construction and it is also an effective way of carbon sequestering.
- Cosmetics and specialized chemical products: Some nice products can be created, but the volumes are far too little to deal with the amount of Sargassum biomass.
- Paper: There are a couple of interesting paper products though added value is very small, but there could be a strategic advantage for use as packaging material for e.g., fruit logistics.
- Cellulose and other Sargassum based fiber products may hold potential for higher value products such as bioplastics and fiberboard.







MAIN CONCLUSIONS

ANSWERS TO OUR QUESTIONS AND MORE









SARGASSUM CLEANUP

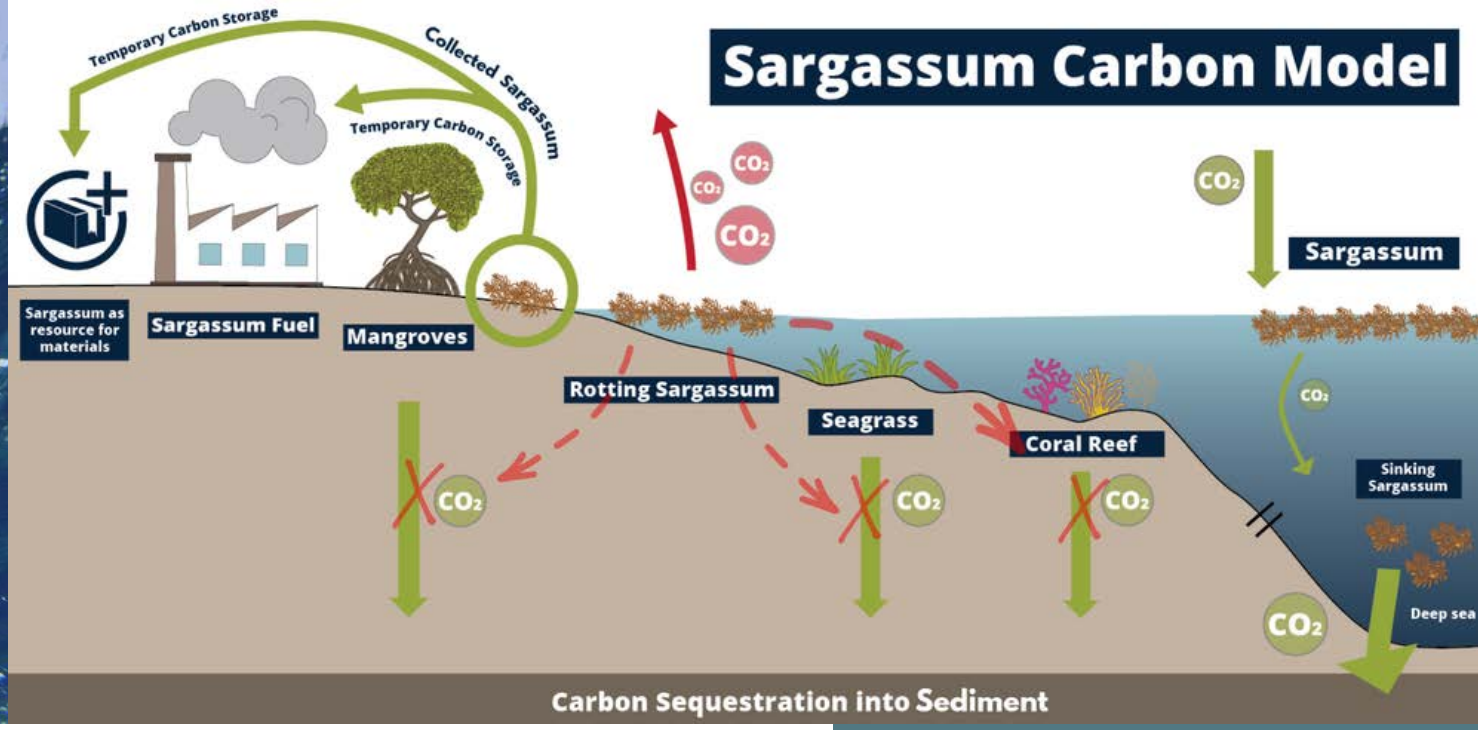
CONCLUSION ON COLLECTING

Answers to our questions

I - WHICH MARINE TECHNOLOGICAL SOLUTIONS ARE AVAILABLE TO COLLECT THE SARGASSUM SEAWEED, THAT ARE ATTAINABLE, SCALABLE, EFFECTIVE AND ENVIRONMENTALLY FRIENDLY?

Based on our findings, collection near shore is the preferred option. Mitigation of beaching is key in order to avoid damaging effects to health, economy and ecosystems in the coastal zone.
The choice for specific maritime equipment depends on local situations. In general, it can be concluded that a combination of booms, vessels and local infrastructure is needed. As for boom technology, 'regular' oil booms may be used, but specifically designed booms for dealing with Sargassum are more effective, and are less prone to overflowing. Booms and technology developed by companies such as DESMI and AlgaeNova are examples of this technology. It is important to investigate the best possible locations to anchor booms. Since booms will only hold Sargassum, vessels will be needed to remove the Sargassum from the sea surface as quickly as possible. Leaving it there too long will cause hypoxia, acidification and leachate. Collecting in a timely manner will also provide the best feedstock. Dedicated 'Sargassum cleanup' vessels are expensive, such as those proposed by companies such as SOS Carbon, DAMEN Shipyards and Royal IHC. Because of the high annual and seasonal variance of Sargassum beaching events, the question is whether such vessels can be made profitable in operation. Therefore a more viable option is using multipurpose vessels and small(er) scale available vessels, as these serve other purposes such as fishing, diving, tourism, or research when Sargassum is not around.





II - WHICH MARINE TECHNOLOGICAL SOLUTIONS ARE AVAILABLE TO USE ON THE SARGASSUM SEAWEED IN SUCH A WAY THAT IT CAN ACTUALLY SERVE AS A CARBON SINK?

There are several options for using Sargassum biomass as a carbon sink. Carbon sinks can be formed by incorporating the carbon of Sargassum biomass into the soils on land, and in sediments of deep oceans. Options for a Sargassum carbon sink on land are biochar, compost and bales. However, challenges facing these solutions are the high salt and heavy metal content. Solutions such as dune fortification with Sargassum bales can be a fairly straightforward way to process large amounts of biomass. However many Caribbean coasts lack dunes where this can be applied.
Technological solutions for a deep sea Sargassum carbon sink are available and are relatively straightforward. It involves pumping to a depth of 200m, and sinking down to depths of over 3000m. The main argument for deep sea sinking is the ability to sequester the carbon stored in Sargassum for almost indefinite periods. Of all the solutions this option has the most potential for quick up-scaling in order to deal with large amounts of biomass. It is important to quickly be able to deal with large amounts of biomass as damage to coastal ecosystems is also very negative in terms of climate impact. Nevertheless, there are legal and ecological aspects that need to be dealt with. We are optimistic about the ecological impact on deep sea communities, but research is needed understand the potential impact and find best methods to minimize these impacts.

CONCLUSION ON USE AS A CARBON SINK

Answers to our questions







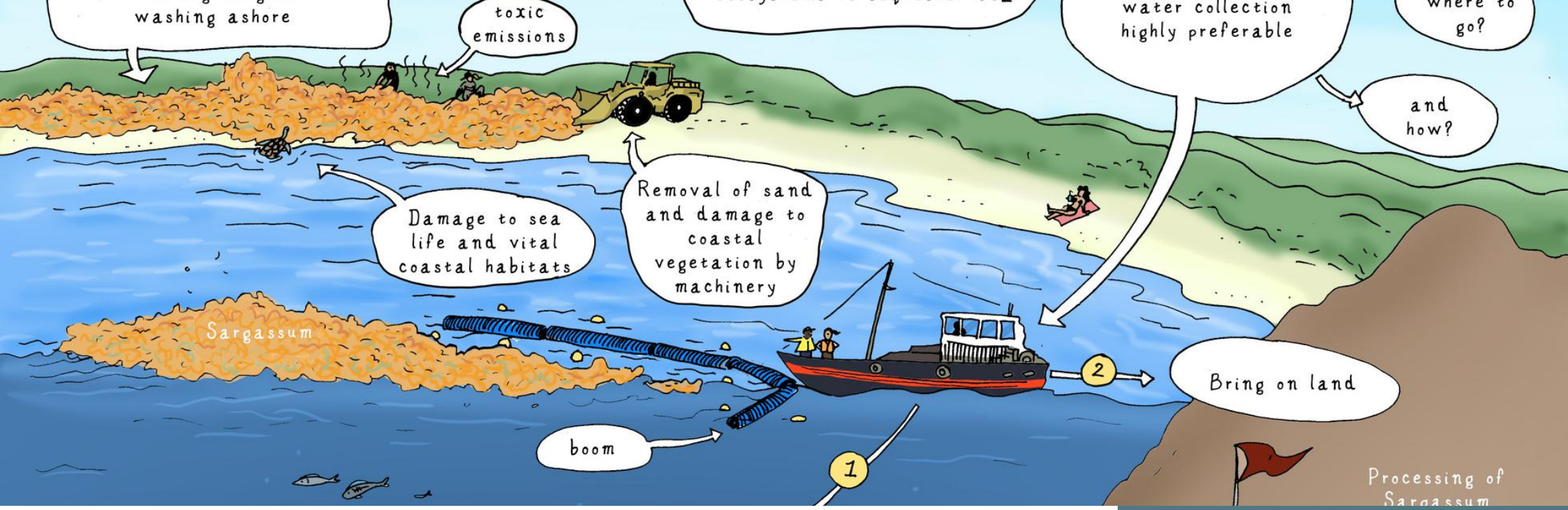
SARGASSUM CLEANUP

CONCLUSION ON PROCESSING

Answers to our questions

III - WHAT ARE THE REAL POSSIBILITIES TO PROCESS HARVESTED SARGASSUM SEAWEED AS A BIOBASED RAW MATERIAL OR BIOMASS?

Numerous applications are being worked on; however, many are still in the early stages, either from a development or funding perspective. On almost all of these suggested applications more research is needed. One option which is not yet viable but holds potential is anaerobic digestion. We feel anaerobic digestion is only viable/scalable when working in saline conditions avoiding use of scarce freshwater. Yields can likely be improved when using different co-feeds and inocula. Super Critical Water gasification technology provides an interesting pathway, and with TNO we will be investigating this using Sargassum collected from Sint Maarten. This technique offers great flexibility through the option of combining with other waste streams and wet saline biomass. These pathways would call for infrastructure to collect food waste and have storage facilities in place for Sargassum. The biggest stakeholders of this application are local energy companies. Legislation on this is key, in order to ensure the green gas produced is actually accepted into the system. The potential of making building materials, such as adobe bricks should get more attention. Many Sargassum derived products do not deal with the full biomass and can leave problematic side/waste streams. However, when these different solutions are combined forming cascading benefits, or develop a biorefinery process in which multiple waste streams can be dealt with, then more value can be derived from Sargassum.



IV - WHAT EFFECTIVE INFRASTRUCTURE IS NEEDED TO SOLVE THE SARGASSUM SEAWEED PROBLEM?

Next to the use and development of the appropriate maritime equipment and infrastructure, accuracy of satellite data and forecasting systems is vital. We used the CLS SAMtool and used the Sargassum Monitoring service. More detail and forecasting is needed, preferably combined with meteorological and other warning systems.
When it comes to transport and processing, working together with island authorities, companies (in particular energy, transport, tourism and building sector) and nature organisations is important. Governments should play a leading role, but they first need to understand the loss of nature due to Sargassum beaching, not only the negative effects on tourism, but also the case for diminished carbon sequestration in these coastal zones. Some islands such as Aruba have large port facilities, much of which is disused, where development of a economically beneficial Sargassum processing facility could be set up. Specific attention should be given to the scale and scalability of the local infrastructure in the region, and on the Caribbean islands in order for economies of scale to work. Therefore, the value of health, ecology and economy needs to become clear and visible for all stakeholders to act appropriately. Initiatives should be supported by an infrastructure which is not only dependent on means available from the 'old economy', but is also funded by carbon credits and the 'economic' value of nature.

CONCLUSION ON EFFECTIVE INFRA-STRUCTURE

How can we do it

TO TRULY TAKE SARGASSUM AS A 'GOLDEN TIDE'

A HOLISTIC APPROACH IS NEEDED
TO MITIGATE, PROTECT AND SEQUESTER

TO COMBINE INTERESTS AND IMPACTS ON
ECOLOGY, HEALTH, COMMUNITY, TECHNOLOGY AND ECONOMY

OVERALL CONCLUSION

SARGASSUM CLEANUP



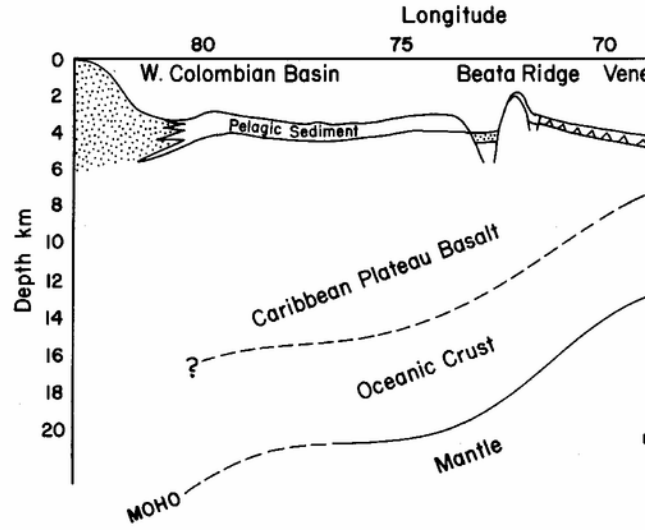


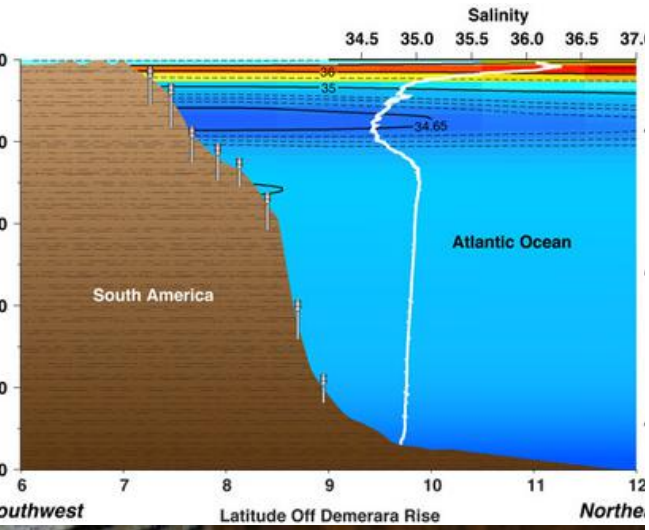
FOLLOW UP PROJECTS
VIABLE & SCALEABLE

PROPOSED PROJECT OUTLINES - FOLLOW UP RESEARCH











DEEP SEA SINK RESEARCH

Project Title: Assessing the Ecological Impacts of Utilising Sargassum for CO2 Sequestration by Sinking to the Deep Sea

Project Lead: PhD study by Daniel Page, Marine Biologist, University of Portsmouth

Aims: This project endeavors to show the natural processes affected and potential ecological impacts, that could be caused by proposed deep sea Sargassum sinking, for CO2 sequestration.It is divided into a series of experiments first starting in the lab, and later moving into the field, following the data yielded in these lab experiments. The results from this project aim to provide a solid basis for further work, eventually culminating in the possibility of using Sargassum sinking in a carbon credit model similar to those in use terrestrially.

Project Outline:
This project is divided into 2 main distinct phases. The first consists of proposed lab experiments, the results from which will be used to gauge the potential ecological impacts the later field experiments may have.

Lab Experiments:

1. Carbon fluxes of live and decomposing Sargassum to create a carbon model.
2. Decomposition of Sargassum biomass conducted under deep sea conditions. (In a pressure chamber, where chemicals, leachate and oxygen depletion will be analyzed)
3. Buoyancy and sinking experiments.

Field Experiments:

1. Core Sample acquisition and analysis, along the Sargasso Sea and Great Atlantic Sargassum Belt (GASB).
2. Sediment trap experiments to track sinking Sargassum under natural and artificial conditions.
3. Oxygen depletion, carbon fluxes and leachate effects are measured from controlled concentrated Sargassum 'dumps'.
4. Effects of different concentrations of 'dumped' Sargassum on deep sea ecological communities.

NEAR SHORE PILOT

Project Title: NeSSP or Near Shore Sargassum Pilot project

Project Lead: Climate Cleanup Foundation

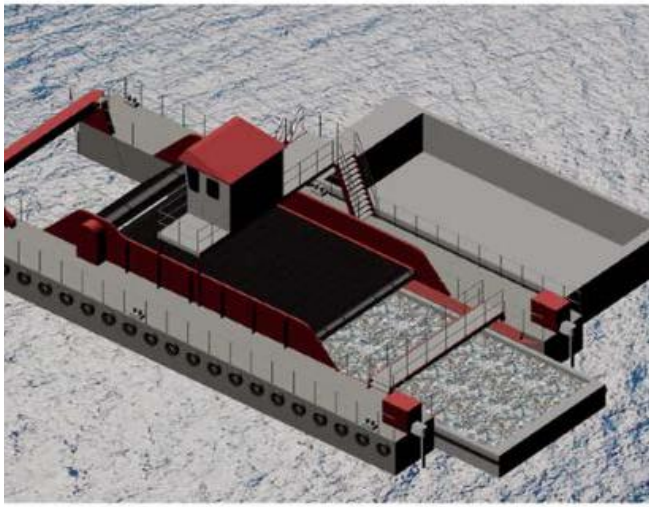
Aims: Based on the information gathered in MIIP018, the Near Shore Sargassum Pilot project will work with marine engineering partners, operators and island organizations on scalable technologies and maritime equipment to safely and efficiently collect Sargassum in near shore zones for either deep sea sinking or further processing on shore.

Context: One of the main findings of the Sargassum Cleanup projects is that near shore collection is by far the best option to solve the problem of Sargassum beaching events. Another element we have learned is that a combination of specifically designed booms combined with adjustable local vessels will be able to play an essential role in this. And above all, local communities should be involved in the execution of Sargassum cleanup projects: they know the area, they can be trained to operate equipment and process the collected Sargassum onshore. This can play a vital role in the diversification of an island's economy.

Project Outline:

- Determine the most effective type of booms
- Determine strategic placement of booms, including information on type of bottom
- Fine tuning monitoring methods in particular from predictive satellite data
- Develop / fine tune harvesting methods that can be incorporated on local craft
- Develop infrastructure for further processing on shore. An essential part of which is to reduce the distance to processing facilities
- Involve and train island professionals and volunteers









BUILD AN INTEGRATED FRAMEWORK

Project Title: Build a framework model for Sargassum, using the three tier Integrated Climate Sensitive Restoration Framework approach, as a sustainable coastal area restoration and mitigation framework.

Project Lead: Climate Cleanup Foundation

Aims: The project aims to combine ecosystems valuation with mitigation and protective action, addressing the problems associated consequences with Sargassum.

Context: Using a multidisciplinary and gendered team is likely to result in improved long-term outcomes for the environment and livelihoods and so contribute to achieving the Sustainable Development Goals. Developing an integrated framework and introducing this into global and national policies, could help stakeholders that deal with Sargassum to develop more robust quantifiable criteria and indicators for success. Such an approach bridges the gap between participatory socio-ecology and digital technology, satellite- and big data, and computational modelling, all of which is used to accomplish the goals of mitigating Sargassum's negative impact, as well as protection and restoring coastal habitats.

Project Outline:

1. Stakeholder analysis, including identifying hierarchies and key contacts, which can be done at the same time as gathering the scientific information
2. Assessing impact and the drivers of collaboration by listening to stakeholders, using triangulation for verification, and checking against the data
3. Bringing all the information together, communicating results and requesting ideas for action.
4. Integrating scientific tools with local socio-economic knowledge and building long-term partnerships with local people
5. Build a Carbon/Impact/Cleanup Model (www.ONCRA.org) - linked to deep sea sinking combining Protection, Mitigation, Restoration, Valorisation.

PARTNERS AND CONTRIBUTORS

OUR SPONSORS, PARTNERS AND SUPPORTERS



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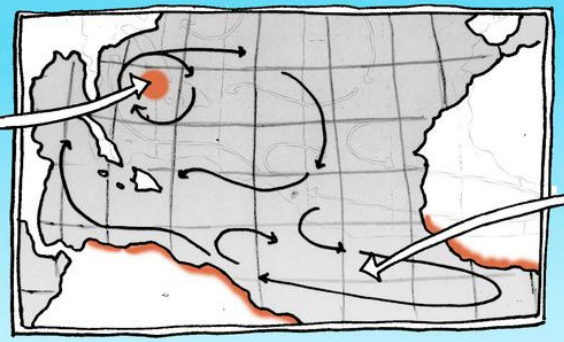
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Sargassum clean-up

climate cleanup



Sargasso Sea

Sargassum seaweed washes ashore in huge quantities causing damage to coastal habitats such as Seagrass, Mangrove and Coral reefs.
This leads to:
- CO_2 and methane emissions from decaying Sargassum.
- Reduced capacity of coastal ecosystems to sequester CO_2.

Preventing sargassum washing ashore

toxic emissions

Near-shore / on water collection highly preferable

but where to go?

and how?

Removal of sand and damage to coastal vegetation by machinery

Damage to sea life and vital coastal habitats

Sargassum

2

Bring on land

boom

1

sinking

Sargassum sinks to the bottom in its natural state

Deep sea

Processing of Sargassum

The next step...

Energy

Product Material

Fertilizer

AM 2020