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Monitoring and evaluation of *Sargassum* collection operations

Summary report

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1 INTRODUCTION

Since June 2014, the French West Indies has been contending with mass strandings of *Sargassum* seaweed, mainly affecting towns and villages on the Atlantic and south coasts of Martinique.

The Prefecture is currently consulting with State services, local communities and agricultural businesses to find immediate and lasting solutions to manage these stranding events.

In late January 2015, ADEME published a call for expressions of interest (EOI) to collect and recover *Sargassum* seaweed with the following aims:

- improve local monitoring and forecasting tools for *Sargassum* influxes;
- define suitable ways to collect washed up *Sargassum* (bay floors, beaches) on land or at sea;
- identify and introduce systems to recover seaweed.

Project promoters had until the end of March to submit proposals to undertake studies, experimental programmes, set up prototypes, test technology for forecasting, collecting, transferring and recycling or re-using *Sargassum*. Ten projects were selected, primarily focusing on collecting seaweed.

At the same time, SAFEGE (SUEZ Consulting) was asked to assess the technical and economic merits of the various methods (pilot projects) and their ability to adapt to different coastline formations in Martinique.

This report presents the conclusions of the various evaluations undertaken.

It comprises:

- a short recap of the background to *Sargassum* collection initiatives;
- a presentation of the evaluation methodology used at the test sites;
- a presentation of findings from the evaluation for each method and an overall assessment chart;
- a decision-making tool.

This report now features points arising from monitoring operations carried out for ADEME Guadeloupe from 2016 to 2019.

2 BACKGROUND TO *SARGASSUM* COLLECTION OPERATIONS

2.1 *Sargassum* stranding events

Since 2011 with the first incidents of mass *Sargassum* strandings on the French West Indies coastlines, further periodic large-scale events were recorded in 2012, 2014-2015 and 2017-2018, occurring virtually all-year-round.

Figure 1: Mass *Sargassum* stranding at Anse Cafard, Martinique, in August 2015 - SAFEGE)

The origins of such strandings remain unclear: "*Scientists think that vast carpets of Sargassum are moving between West Africa, Northern Brazil and the Lesser Antilles. This flow may have been triggered by severe climatic fluctuations in 2010 when it is thought to have created a new, different, loop yet similar to that observed for many years in the South Eastern United States and the Greater Caribbean.*

The phenomenon may stem from the combined effect of wind and surface currents together with nutrients absorbed by the Sargassum. The nutrients derive either from flows discharged into the sea from large rivers or from Saharan dust particles."

Some 1 million m^3 of *Sargassum* was estimated to have washed up in Martinique and Guadeloupe during the calamitous period of 2014-2015. [1]

Key points to note

Mass sargassum strandings in Martinique are linked to a relatively unknown phenomenon. ***This phenomenon is extremely random making it challenging to introduce a management plan****:*

- *unpredictability of stranding sites and timings;*
- *incidents vary in length (one-off or long periods);*
- *highly variable amounts of sargassum.*

[1] François COLAS-BELCOUR, Tristan FLORENNE, François GUERBER (July 2016), "*Le phénomène d'échouage des Sargasses dans les Antilles et en Guyane*", CGEDD Report No. 010345.

2.2 Stranding incidents

Stranding incidents fall into three categories:

- public health;
- economic;
- environmental.

2.2.1 Public health impacts

When *Sargassum* decomposes in moist conditions (anaerobic fermentation), it generates hydrogen sulphide 'H_2S) which has a distinctive "rotten eggs" smell, even in minute quantities.

H_2S is one of the most hazardous known gases. It is a swiftly acting toxic substance. Depending on the level of exposure, it can[2]:

- inflame mucous membranes in the eyes, the respiratory tract and bronchioles upon repeated exposure;
- result in unconsciousness and then coma above 500 ppm;
- be lethal if inhaled in large volumes (>1000 ppm).

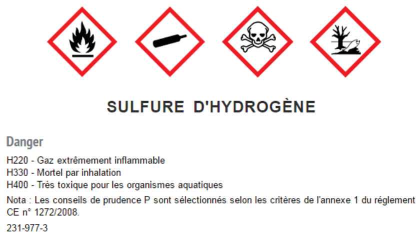


Figure 2: Data safety sheet No.32: H_2S (www.inrs.fr)

In its deliberation of 17 February 2016, ANSES stated that, to date, no epidemiological foresight study has been carried out on the health effects of chronic exposure to H2S and to other molecules released from rotting *Sargassum*, even in low doses.

The French Public Health Council issued guidance on 8 June 2018 to define management measures for the exposure of French West Indies communities to ammonia (NH3) and hydrogen sulphide (H2S) from decomposing *Sargassum* seaweed.

Many reports from stranding sites have mentioned manual clean-up teams experiencing nausea and headaches, especially during initial interventions (see section 0, p31); also, local communities living in those coastal zones mentioned similar symptoms.

[2] "*Guide pour la protection des travailleurs exposés – Algues vertes*" (green algae worker protection guide), March 2012, DIRECCTE BRETAGNE.

Points to note

H_2S is only produced from anaerobic fermentation (seaweed heaped into piles over 10 cm thick, or rotting underneath a hard crust, e.g. windrow) on land or at sea, in the presence of moisture.
Rapid disposal of the seaweed or spreading out the piles helps counter these effects.
Any operations to collect mass strandings must be undertaken in conditions to control H_2S risks.

2.2.2 Economic impacts

Mass *Sargassum* strandings cause:

- **Onshore**:
  - a nuisance to tourism (unusable beaches and foul smells, etc.); significant harm to the image of sites where business from tourism is a mainstay for the local economy, resulting in a drop in visitor numbers in the short, medium and long-term;
  - a nuisance for local residents (foul smells, health problems, etc.) leading to activities being altered or transferred (e.g. temporary closure of Robert 3 Secondary School, Robert) or communities relocated;
  - deterioration to specific equipment and material by H_2S (metal corrosion, including copper and copper alloys used in electronic circuits): pipes, domestic appliances, high tech devices, etc.;
  - depreciating property asset values in affected areas;
  - clean-up and management costs.

- **Offshore**:
  - a nuisance to fishermen (torn nets and broken propellers, movements impeded or blocked, anoxic conditions in fish farms, etc.);
  - a nuisance for nautical leisure activities (windsurfing, kayaking, swimming, etc.).

Estimating the relative costs is complex. A 2015 CCIIG Guadeloupe survey of 424 businesses depending on tourism and fishing indicated that 148 of them had been hit, amounting to an estimated cost of 4.6 million euros for the first quarter of 2015.

An initial estimate by the CCIM (Martinique Chamber of Commerce and Industry) published in May 2018 revealed the cost of damage to the nine worst-hit coastal communities to be equivalent to 1.5 million euros.

Points to note

Without proper collection and disposal facilities, mass strandings of sargassum seaweed onshore and offshore have a highly detrimental effect on the local economy *(tourism, fishing, property business, etc.).*

2.2.3 Environmental impacts

Mass strandings of *Sargassum* can cause[3]:

- **Onshore**:
  - physical obstacles to movement of animal species, particularly sea turtles;
    - problems at egg-laying times when females can be blocked on the shore without space to lay their eggs;
    - young turtles being blocked or slowed in reaching the water, raising their already high mortality rates[4];
  - alterations to hydro-sedimentary equilibriums (modifications to beach accretion/erosion phenomena) and related ecosystems;
- **At sea, near the shoreline**:
  - reduced light levels and anoxia due to high oxygen consumption, harmful to the existing ecosystems (seagrass meadows, corals, etc.);
  - altered chemical equilibriums (organic matter, sulphates, etc.).
- **Offshore**:
  - according to the published literature, *Sargassum* 'rafts' are highly beneficial for biodiversity as they act as nurseries, providing shelter and sustenance for many species. They play a similar role to that of FAD (fish-aggregating devices) used for fishing.

Points to note

At sea, sargassum 'rafts' provide high environmental added value *due to the role they play as nurseries, providing shelter and food for many species (a similar role to that of FAD).*

On land, sargassum, in small quantities, has a positive effect on the coastal environment *and remains a natural phenomenon. Seaweed helps stabilise beaches by favouring plant growth and provides food and shelter for a wide range of species.* ***It becomes a problem when there are mass stranding events on the coast and when it stagnates, as the natural environment is no longer able to absorb it without harmful physical and chemical changes to existing equilibriums.***

3 DEAL Martinique "*Echouage des sargasses pélagiques sur les côtes martiniquaises et impacts sur les écosystèmes littoraux : poissons associés à la sargasse et impact sur les mangroves et herbiers*." 2011

4 Ga-Young Choi and Karen L.Eckert "*Manual of Best Practices for Safeguarding Sea Turtle Nesting beaches*." WIDECAST, Technical Report No.9, 2009.

2.3 Conclusion

Key points to note

Mass strandings of sargassum have highly detrimental health, socio-economic and environmental effects*, whether they come ashore or gather at sea close to the shore.*

It is therefore vital to identify the most effective collection procedures (onshore and offshore) to use based on criteria-specific stranding conditions:

- ***technical****: Feasibility, yields, safety of people and property;*
- ***socio-economic****: Estimated costs, jobs;*
- ***environmental****: Impact of the method on the natural environment.*

The purpose of this document is to evaluate collection methods, including those selected by ADEME in its call for project proposals.

3 MISSION METHODOLOGY FOR MONITORING AND EVALUATING COLLECTION OPERATIONS

3.1 General methodology

The methodology used stems from research by CEVA (centre for the study and promotion of algae) based in Pleubian, in the Côtes d'Armor.

In conjunction with ADEME Martinique, the CEVA has produced:

- a methodological evaluation guide for seaweed collection, attached to APPENDIX 2 of this document;
- and run a field-based training session in August 2015 in Martinique, which SAFEGE attended.

The methodology used for the present project is directly based on that presented by CEVA. The various points to note are summarised in the table below**. The full methodology is attached to APPENDIX 2.**

An on-site assessment form has been developed to gather information required for the evaluation. This form is attached to **APPENDIX 3** of the present document.

Summary fact sheets on the various methods observed are attached to **APPENDIX 4** of the present document.

ATTRIBUTE	CONTENT	METHODOLOGY	LIMITATIONS
Collection operation circumstances	<u>Site description</u>: ➢ Accessibility (path, road, slipway), ➢ Site type (beach, ends of bays mangrove, etc.), complexity (obstacles present, etc.), ➢ Type of stranding (date, distribution ➢ Evaluation of the seaweed mass	Visual remarks Manual reading of stranding size (length, breadth, height) Manual reading of 1 min drained weight /volume m²	Readings limited to the beached seaweed stranding; Evaluation inaccuracies of masses linked to non-uniform stranding distribution.
	<u>Equipment description</u>: ➢ Collection type (manual/mechanised); ➢ Collection area (onshore and/or offshore); ➢ Tools (type, size, position, etc.); ➢ Operating depth; ➢ Storage/transfer method; ➢ Other	Visual remarks Technical fact sheet Project promoter interview	-
	<u>Description of collection arrangements:</u> ➢ Labour force, ➢ Organisation of collection stages	Visual remarks Project promoter interview	Changes to the organisation from one collection task to another (adaptation)
Yield assessment	<u>Definition</u>: ➢ Gross yield (m3 collected per hour) ➢ Integrated yield (m3 collected, transferred, removed per hour)	Timing of collection, transfer and disposal stages Estimated collected quantities	Changes to the organisation from one collection task to another (adaptation) Collection/disposal services that can be separated (time/operators). Inaccuracies linked to visual estimations due to a lack of weighing devices.
Efficiency of collection techniques	Change in biomass stocks before and after collection task.	Visual remarks Manual reading of stranding size (length, breadth, height) Manual reading of 1 min drained weight /volume m²	Inaccuracies in sizes linked to non-uniform distribution of strandings Inaccuracies from the method being applied inconsistently at the site. Rapid reformation of seaweed mass on land.
Selectivity of collection techniques	<u>Definition</u>: ➢ Wet-dry weight ratio ➢ Collected sand mass/volume ratio ➢ Materials collected other than just seaweed?	Visual remarks Manual determination of various ratios per sample and analysis (separation seaweed/sand, drying)	Natural drying (sun for in-situ conditions) influenced by weather (showers, etc.) Specific findings based on nature of seaweed collected (fresh/old, etc.) and collection depth (surface/at depth)
Environmental impacts	<u>Definition</u>: ➢ Potential impacts fauna/flora/milieu ➢ Operational constraints	Visual remarks Bibliography	Estimation of impacts (complex measures)
Outcome of transferred seaweed	Identification of a seaweed disposal point	Inventory of collection arrangements	Reporting back complex information as collections/disposal procedures could be separate (time/operators).
Impacts on society	Impacts on the community (jobs, problems, difficulties, etc.)	Visual remarks Bibliography	-
Economic evaluation	Response costs (staff, materials, etc.) Disposal costs (hourly rate per m^3 disposed of)	Timing of collection, transfer and evacuation operation stages; Costings sent	Variable cost based on sites (proximity to disposal point, resources available, etc.)

3.2 Type of arrangements adopted

The evaluations were undertaken by a SAFEGE engineer. The standard activity evaluation protocol is shown below:

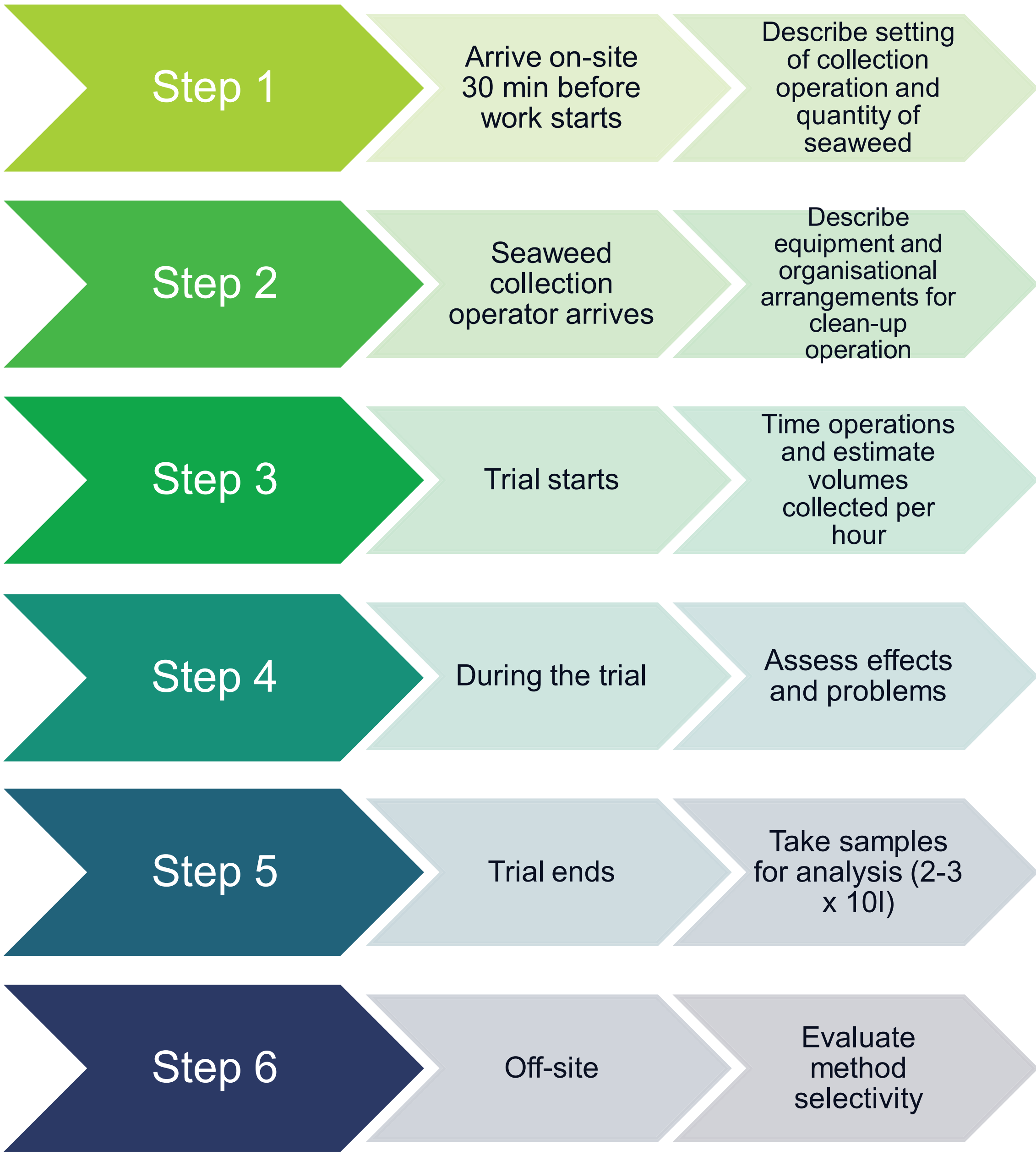


Figure 3: Standard activity plan for an evaluation exercise

3.3 Equipment used

The list of equipment used is shown in the table below:

SUBJECT	Equipment
Safety	Cartridge gas mask
	H_2S gas detector
	Protective boots
Measurements	Camera
	Stopwatch
	Quadrants
	Tape measure
	Mesh bags
	Scales (bathroom)
	Precision scales
	3 x 10 L measuring buckets for collection
	Hand-operated wringer
	Storage box to dry seaweed naturally

4 MONITORING AND EVALUATION OF COLLECTION OPERATIONS

As part of the mission to monitor and evaluate collection methods arising from the call for expressions of interest published by ADEME, several collection methodologies were selected and tested in Martinique and Guadeloupe. Some methods outside the call for projects were also evaluated. These methods fall into 5 categories:

- offshore **barriers**;
- mechanised **offshore collection**;
- manual **onshore collection**;
- mechanised **onshore collection**;
- collection **assistance equipment**;

The list of equipment inspected is shown below.

Table1: Summary of methods observed

Categories	Organisations	Tools
Offshore barriers	ALGEA NOVA	Boom with mesh skirts
	Association STOP SARGASSE	Modular cubic floats + mesh skirt
	Robert Municipality / SDIS	Stakes and wire mesh or netting
	Frégate Est 2 / FILETDROM residents group	Polystyrene floats - plastic mesh
	RISK	PVC boom with skirt
Mechanised offshore collection	ALGEA NOVA	Harvesting barge
	SEREG / Robert Municipality	Small pick-up barges
	SGM	Amphibious vehicle and pumping system
	ELBE	Trailing suction hopper dredger
	SOTRADOM	Offshore harvester
Manual onshore collection	CAID Patrimoine	Shovels, forks and wheelbarrows
	RSMA	
Mechanised onshore collection	SEEN	Surf rake
	AXINOR	Self-propelled harvesting vehicle
	LE PROGRES Cuma	Cane loader
	Various	Long-arm excavator
	Various	Mechanical digger
Collection assistance	BAMITEL JACOMETI	Amphibious vehicle
	SEEN	Beach groomer

Section 5 contains a summary of findings from trials conducted.

4.1 Offshore barriers

4.1.1 Generalities

4.1.1.1 Aims when setting up barriers

Installing offshore barriers can target two objectives:

- **Containment at sea (storage)**: The raft of *Sargassum* collects along the length of the barrier and is trapped until gathered by offshore harvesting methods or until it disintegrates in-situ and sinks without being collected. The barrier can be open or closed:
  - **An open system** (blocking barriers) keeps the floating mass at sea but this is highly dependent on its positioning, size and regular current patterns. If the latter changes it could shift the mass outside the containment area and in these circumstances, the barrier is subjected to maximum pressure. The barrier can also be bypassed once full.

    Based on monitoring undertaken, seaweed amassed behind these barriers ends up sinking and possibly affecting natural environments if there is poor water recirculation. Seaweed can also pass under floating barriers with bottom currents. It is therefore better to harvest seaweed behind the barrier to avoid these incidents and properly identify the area to set up the barrier to avoid the effects of decomposing seaweed.
  - **A closed system** concentrates and diverts the seaweed. It protects part of the coast from strandings regardless of the size of the mat and current direction but it cannot stop beachings at its edges.

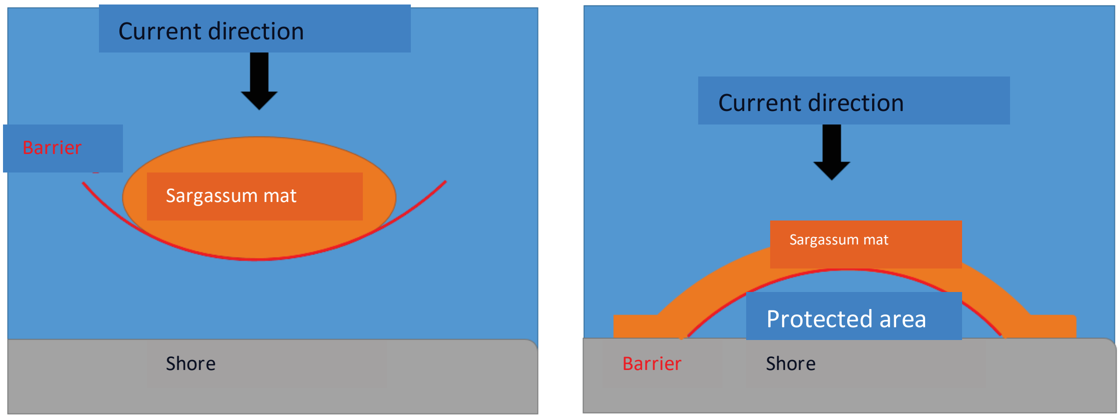


Figure 4: standard set-ups for a barrier system designed to contain *Sargassum* (open system on left and closed system on right)

Figure 5: Illustration a closed system barrier (source: AlgeaNova, Dominican Republic, May 2018)

- **Diverting seaweed**: The *Sargassum* raft "slides" along the barrier with the current to a preferred beaching site (onshore collection). The site can be equipped with a fixed collection facility or be easily accessible for onshore collections.

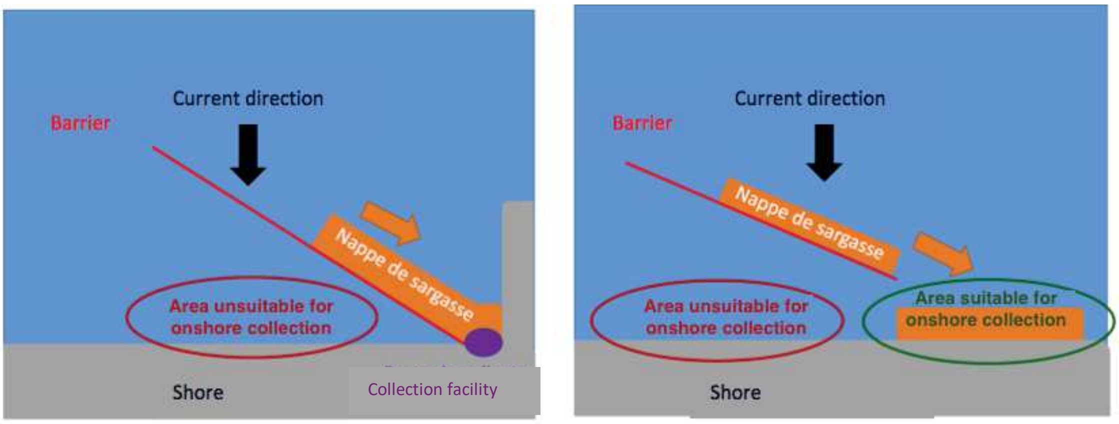


Figure 6: The principle of a diversion barrier (diverting seaweed to a harvester (left) and a beaching site (right)) *(Nappe de sargasse* = Sargassum *mat)*

Setting up a barrier system can be especially useful to protect:

- **Sites with significant human, economic or ecological implications**: schools, residential areas, hotels, mangroves, etc.
- **Sites where onshore clean-ups are not possible**.

4.1.1.2 Points to remember when setting up a barrier system

Setting up a barrier must be well planned in advance to address:

- **The shape and size of the barrier**: Based on the desired objective (containment and/or diversion), prevailing wind and current direction and the presence of any competing aquatic activities (boat movements, jet-skis, etc.).
- **Anchoring systems required**: Helix moorings and buoys, etc. The choice depends on the type of seafloor substrate (mud, sand, etc.).
- **The number and size of anchors**: Depending on desired shape, current strength, swell, bathymetry and likely forces on the barrier such as the mass of water and weight of the *Sargassum* mat (especially for confinement barriers).

- **Installation and dismantling times**: In the event of extreme weather conditions or barrier resistance limits being exceeded (cyclones, powerful swells, etc.). The barrier must be easy to dismantle/install to prevent breakages that could result in all material being lost and environmental pollution (e.g. plastic barrier debris). All coastline barriers must account for these hazards at the same time.
- **Barrier resistance and ease of maintenance**: The barrier will be subjected to numerous constraints (swells, UV rays, chlorides, possible impacts with buoys, combined force of currents and the mat of seaweed, colonisation by aquatic flora and fauna, etc.). These constraints can lead to the barrier components breaking down more or less rapidly and therefore a significant need to replace materials or risk a comprehensive loss of performance. As such, a skirt or mesh will be less resistant to water pressure while interchangeable modular structures will be more likely to be easily replaced when worn or damaged.
- **Floor space**: As barriers can stretch several hundred metres, solid structures (especially, floating systems) require a larger surface area than inflatable systems (input volumes, floor area to store spare parts or removal of barrier in unfavourable weather conditions).
- **Landing points (land-sea couplings):** When a barrier is set up to confine seaweed with its starting point being on land. In this case:
  - Seaweed must not bypass the barrier with the tide, so the barrier must rise and fall the tidal range. Current patterns are therefore a key parameter to consider.
  - Barriers can be worn or damaged if positioned close to the shoreline, e.g. a float rubbing against rocks, etc.

Points to note

We will not specify anchoring characteristics in the rest of the report (type and size) as these are not specific to a barrier model but rather to a site based on its bathymetry, the substrate and currents, etc. Two barriers of the same model and size might require a completely different anchoring system depending on where they are sited.
Anchor systems must be sized beforehand by an appropriate body to ensure barriers are held firmly in place.

According to French regulations, only "A-grade" deep-sea divers are allowed to undertake construction works. B, C or D-grade deep-sea divers and recreational divers are not allowed to undertake any underwater work tasks.

It should be noted that apart from barriers designed to fully divert mats of seaweed, a coupling with the harvesting system is recommended, especially in the event of mass strandings. The build-up of seaweed leads to the mat getting gradually thicker. This was observed in the Dominican Republic, where mats reached 60 to 80 cm thick in barrier zones running perpendicular to the current.

Excessively thick mats lead to:

- A sharp rise in force exerted on the barrier that could cause it to snap and become useless. The sums invested in barrier systems therefore serve no purpose and sites requiring protection are invaded by mass strandings.
- A thin layer of *Sargassum* on the surface which is temporarily lifted out of the water by underlying layers. In calm waters, this layer will tend to dry out and form a crust partially limiting oxygen exchanges and subsequently increasing the chances of the seaweed mat rotting in-situ.
- The bottom layer of *Sargassum* experiences anoxic conditions and no light which eventually kills it and leads to anaerobic decomposition (generating soluble H_2S). This layer tends to sink and can therefore gather on the seafloor and rot. Alternatively, it can be scattered and wash up on the coast from bottom currents (beaching).

The use of containment or blocking barriers must only be considered if the water circulation is being renewed sufficiently so that the seawater's physical and chemical parameters are virtually unaltered by rotting *Sargassum*.

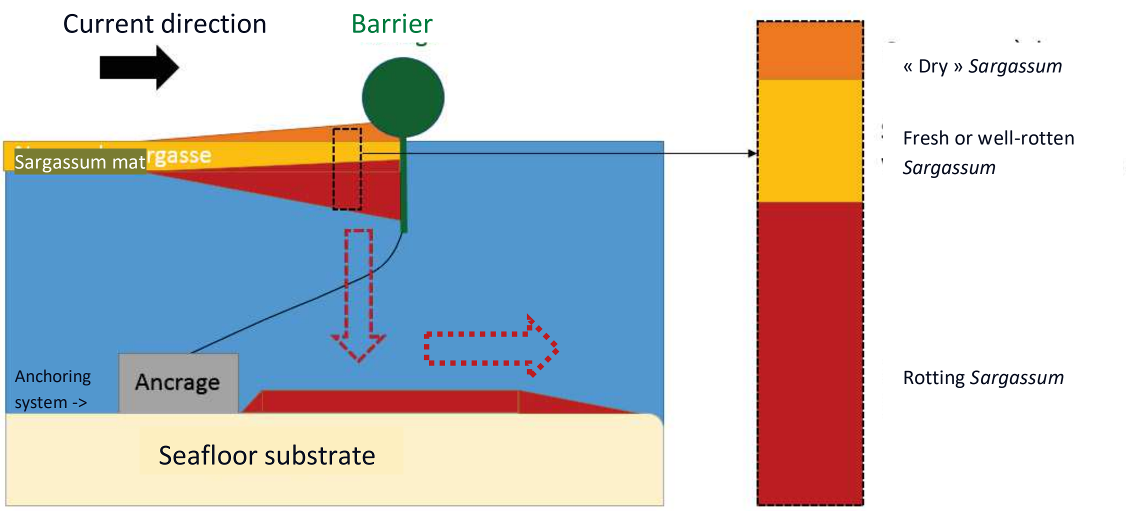


Figure 7: Diagram showing the operating principles observed in a mat of *Sargassum* seaweed building up when coming into contact with a floating barrier

When a barrier set up in the Dominican Republic was evaluated, five effects were noted that should be common to all barriers:

- **EFFECT 1: Gulley erosion**. This is probably linked to changes in current patterns in the water blade, an obstacle created by the barrier. This erosion effect under the barrier has been observed at a floating barrier positioned at 1.5 - 2m depth with a 1m-long apron. Although it should be less perceptible when the sea is deeper, gulley erosion does cause:
  - The disappearance of seagrass meadows that existed before the barrier was set up.
  - The creation of an area where seaweed that sinks straight in front of the barrier can collect.

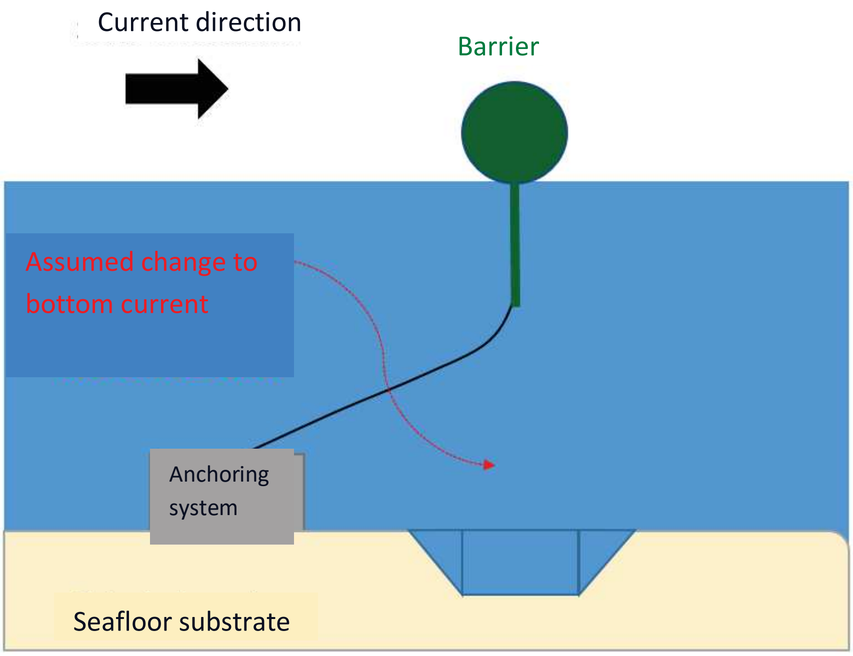


Figure 8: Diagram showing the erosion process observed underneath the barrier

- **EFFECT 2: An accretion effect in the protected area**. According to local residents, the protected area of the beach gradually increases in size. This phenomenon could be due to calmer swells and undertow in the protected area, which favours accretion;
- **EFFECT 3: A reduction in artificial beach erosion** by less need to gather beached seaweed.
- **EFFECT 4: A FAD effect** (fish aggregating device) by maintaining a mat of un-decomposed seaweed on the surface, providing shade and shelter. The gradual colonisation of parts of the barrier by seaweed, molluscs and crustaceans also seems favourable to this effect.
- **EFFECT 5: The passage of a small part of seaweed under the floating barrier**. This seaweed appears to come from that which dies when it comes into contact with the barrier, sinks and washes up on the beach by bottom currents. The amount observed was very low and presented no risk of anaerobic decomposition. The presence of this small amount of seaweed can actually be beneficial to the local ecosystem (beach stabilisation, source of food for wildlife, etc.).

4.1.2 Presentation of various barriers observed

Points to note:

The following observations given in the next part of this section are from on-the-spot inspections. ***Given that the true effectiveness of a barrier must be assessed over time, these observations may be subject to change****. Furthermore, comparing the performance of different types of barriers is not particularly straightforward given the many external parameters to consider (climate, substrate, ocean conditions, etc.). A summary of strengths and weaknesses together with possible key points to keep in mind with these methods is given at the end of this section.*

4.1.2.1 AlgeaNova anti-*Sargassum* barrier

The anti-*Sargassum* barrier installed by the AlgeaNova company is a model now produced on an industrial scale. It was positioned opposite the Westin Hotel in Punta Cana in the Dominican Republic (see Figure 4). This barrier was inspected on-site from 25 to 29 May 2018.

Figure 9: ALGEANOVA anti-*Sargassum* barrier

This barrier comprises 6m modules (9m for the finalised version), each made of:

- a 350 mm diameter inflatable boom, protected by a flexible PVC sleeve and a second micro-mesh coating (to protect against floating debris) serving as a float. All parts are UV-treated;
- a 1m skirt below the barrier made of 25mm diameter textile mesh;
- A 0.13 mm-wide net screen with 25mm diameter openings above the boom designed to prevent seaweed passing over the barrier in rough seas (swell).
- A dual fastening system between modules using Velcro and shackles and thimbles (2) which help keep them watertight from seaweed (Velcro strip) while ensuring the barrier remains stable under the weight of seaweed and sea conditions (shackles).
- It is anchored every 3m (helix moorings and buoys subject to substrate) with a 20 mm chain linking the barrier anchoring points weighing 7 kg per metre. The anchoring chain is connected to the mesh by shackles and thimbles and galvanised steel clips. Vertical skirt stiffeners at the anchoring points reduce tugging on the mesh from the latter.

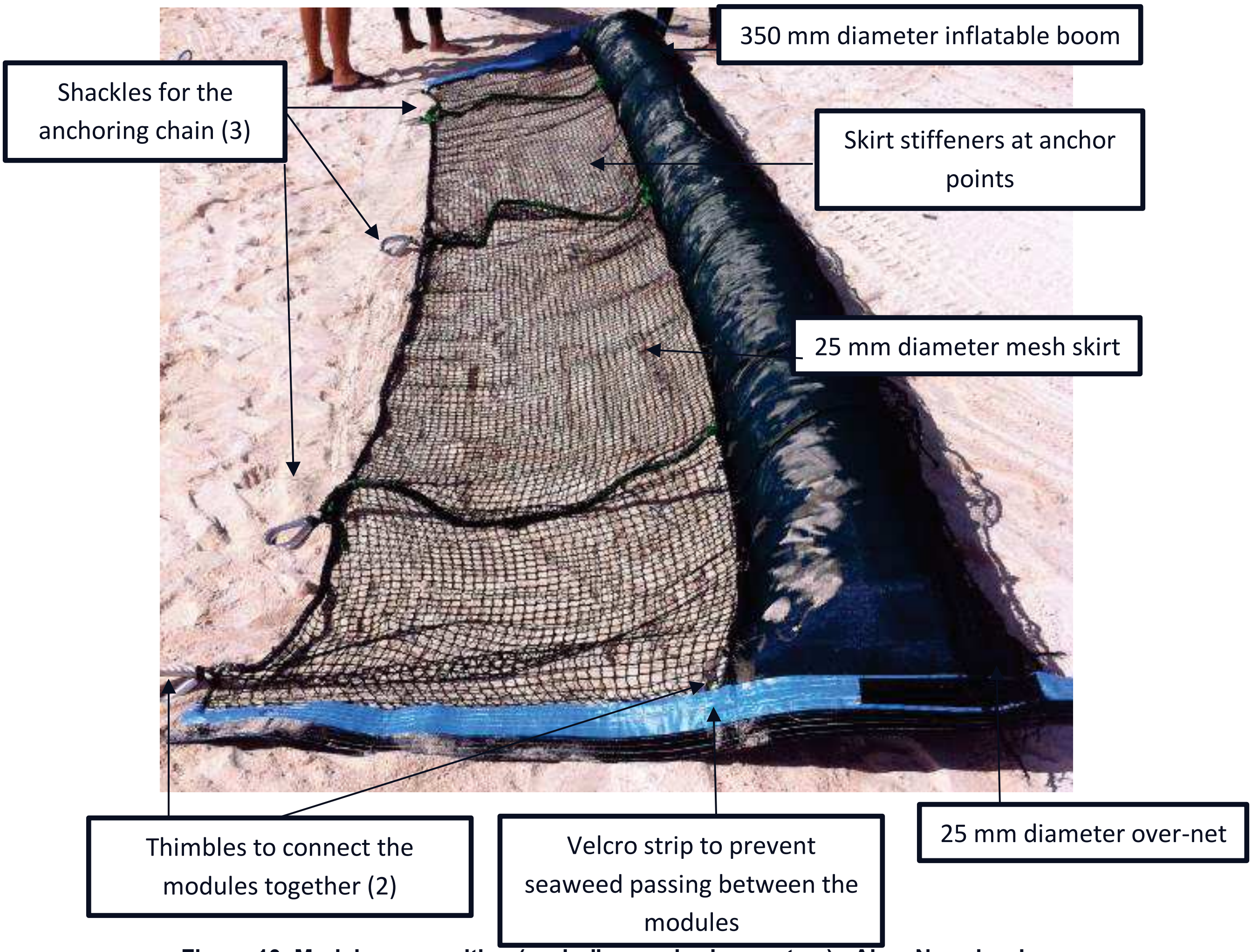


Figure 10: Module composition (excluding anchoring system) –AlgeaNova barrier.

Velcro strip prevents seaweed passing between the modules

Shackle between two thimbles

Figure 11: Inter-module connection system –AlgeaNova barrier.

The barrier is designed to be installed:

- Directly from the sea, without any particular arrangements
- From the land, starting on the beach to prevent seaweed getting around the barrier with the tides. The barrier has a fixed section starting on the beach.

Figure 12: Illustration of a barrier set-up from the beach – AlgeaNova barrier.

- From a cliff using a vertical rail to attach the modules, enabling the barrier to rise and fall with the tide. This set-up was not observed at the time of the inspection.

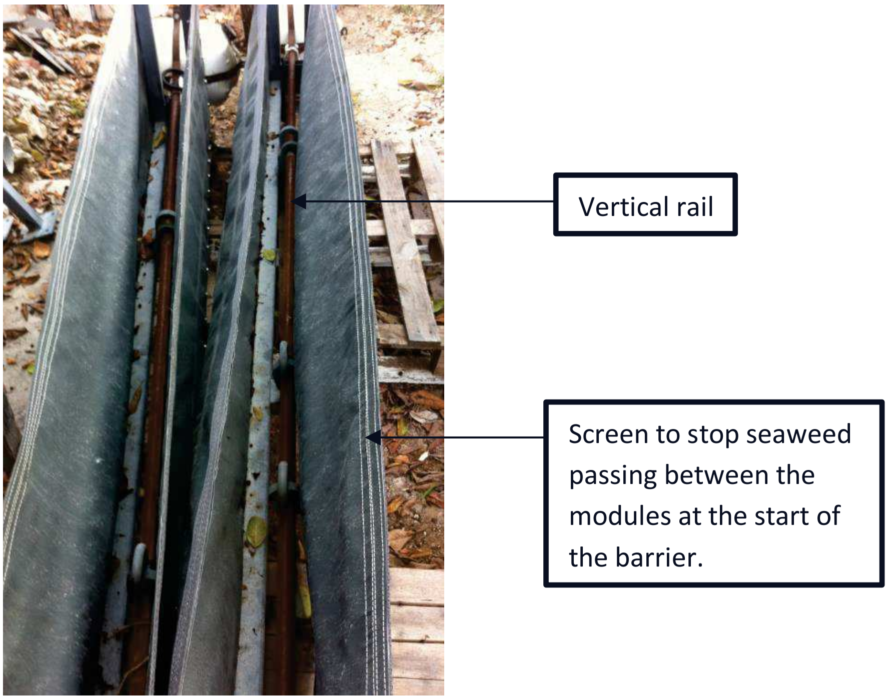


Figure 13: Illustration of a vertical rail – AlgeaNova barrier.

The barrier can be cleaned using mechanised equipment. The company has introduced a catamaran-type cleaning vehicle ("Projinova Cleaner") fitted with two rotating brushes and a tailored central guide rail. This enables the vehicle to pass over the barrier and brush it, thereby reducing aquatic flora and fauna colonising the mesh. Adding the Projinova Cleaner to the barrier uses special modules at the start and end of the barrier fitted with a zip to open it periodically to avoid removing and refitting the modules. The system helps clean the barrier over long distances with minimum human effort. According to the constructor, maintenance once a month is sufficient.


Figure 14: Projinova Cleaner (left) – Start of mesh colonisation (right)

If part of the barrier is damaged, its 9m modules can easily be replaced.

The barrier's inflatable system also takes up less space when it is transported or stored on land, thereby reducing transportation.

According to the manufacturer's data, the barrier has been scaled to operate up to the following conditions, after which the barrier must be removed:

- Wind: 25 knots
- Swell: 1.5 m

The costs shown below are taken from the manufacturer's data **and are for indicative purposes only**:

- Total cost: approx. €480/ml excl. tax :
  - Cost of the floating barrier (excl. anchoring, installation and transport): approx. €130/ml excl. tax
  - Supply and fitting anchor points, including connecting the barrier together: approx. €35,000/100 ml – (€350 m/l)
- Cost of Projinova Cleaner: €150,000

During the evaluation task, the barrier was set up close to the coast (1.5 – 2 m average depth) in an area experiencing a large swell (but protected by the coral reef) with strong currents. Regular *Sargassum* strandings 3 to 5 m wide have been observed building up along the barrier. A 0.6 to 0.8m thick layer of seaweed was periodically observed in direct contact with the barrier, in the area running perpendicular to the current.

Key points to note

During the inspection visit, the barrier was experiencing regular sargassum strandings in an area close to the coast with a swell and currents also present. No particular fault was observed during the inspection period (movement of the barrier, module splitting, considerable wear and tear to equipment, etc.). The barrier was fulfilling its role of containing mass strandings. Initial trials of private anti-sargassum barriers installed by AlgeaNova were held in 2015 and led to several alterations resulting in the current version (addition of an over-net, micro-mesh sleeve and net stiffeners at anchoring points to avoid tears, etc.)

The barrier installed by AlgeaNova features several key advantages:

- A barrier manufactured on an industrial scale that can be ordered in large quantities.
- A structure comprising 9m, **easily installed and replaceable modules**, with fixings to other modules and anchor points using simple shackles and Velcro strips. This helps cut removal and reassembly times in bad weather.
- A 1m mesh skirt helps **reduce the pressure exerted on the barrier by currents**. The height of the skirt also helps contain thick layers of sargassum seaweed.
- The barrier is also anchored every 3m which helps **spread the forces acting on the barrier as much as possible**, to reduce "pocketing" and keep the skirt straight (unmaintained, the skirt can trap animals);
- The 25mm diameter mesh **reduces the risk of species** (such as turtles) **becoming trapped** (source: *Guidelines to cut sea turtle mortality rates in fishing operations. Rome, FAO 2013. 132 p*) ;
- the Projinova Cleaner brush cleaner device has been specifically designed for this type of barrier to **cut the time and labour required to maintain the barrier**, especially over long lengths.

The costs of the materials are, by contrast, expensive compared to other barriers evaluated.

4.1.2.2 RISK anti-*Sargassum* barrier

This anti-*Sargassum* barrier installed by the RISK company for the call for projects issued by ADEME Martinique is an industrially-produced Goeland curtain boom barrier manufactured by RCY[5].

The Marigot barrier:

Figure 15: RCY floating barrier (Goeland 200 curtain boom barrier)

This barrier comes in 25 m modules, each comprising:

- a cylindrical 150 mm boom made of PVC fabric containing a series of separate closed cell polyethylene foam cylinders;
- a solid 0.4 m PVC fabric skirt tethered by a galvanised ballast chain (1.7 kg/ml) in a sheath. The chain absorbs the strain on the barrier up to 5 tonnes before it breaks. A 1m skirt was initially designed for the barrier but replaced as it had too high a drag in the water (solid skirt).

Two modules are coupled as follows:

- by polyamide connector plates bolted to the freeboard and draft;
- by a shackle connected to the ballast chain.

Figure 16: View of a connection point between two modules

[5] RCY brand: REYNAUD CAUVIN YVOSE

This barrier was deployed at the mouth of the Port of Marigot on 21/08/2017. The goal was to divert the seaweed and contain it near the slipway to make it easier to collect and prevent it accumulating at the bottom of the port. Two overlapping sections were installed. The 1m skirt on the initial barrier was shortened to 0.4 m as the drag in the water was too great (solid skirt).

Figure17: Diagram showing the principle to set up the barrier

- Wear and tear was observed to the northern section, straight in front of the tethering point (torn skirt). This damage was due to the barrier rubbing against rocks in swells or changing tides.
- Pocketing in the southern section was quickly noted, which stopped the barrier from fulfilling its intended role. Hooks fitted to the barrier were not strong enough to stop the section distorting.

Figure 18: Photo showing how the barrier is installed

The barrier had to be subsequently withdrawn on 03/09/2017 due to an AMBER warning for heavy swells linked to Hurricane Irma. It was not put back until 27/09/2017 due to bad weather. Intermediate mooring buoys were added to the southern section (1 every 6m) to stop it from distorting.

The inspections carried out by the company on 28 September, 1, 2 and 6 October found no specific problems but an anomaly was noted on 9 October in the southern section due to the mooring buoy hook suddenly shifting. The sea conditions were normal during this period so the reason for the mooring buoy shifting was unclear. It may have been due to currents, a fishing skiff hitting it or a third party deliberately moving it.

The barrier at Robert (Pointe Hyacinthe)

A new type of RCY barrier was installed at Pointe Hyacinthe, near Robert, in early July 2018 and is now managed by the municipality.

A site visit was made one month after it was installed, which found the skirt and chains to be fouled with molluscs, seaweed and corals.

Figure 19: View of the RCY barrier skirt after not being cleaned for one month.

Findings from the on-site inspection coupled with the supplier's product overview indicate that RCY Goeland 200 barriers are best used in relatively calm waters (ports, rivers, lakes) and not on the high seas or off the coast. As the barrier is designed to not be used in strong swells and exposed to considerable forces (e.g. seaweed pressure + current), it should be used in more sheltered locations on the shore (ports, Trou de Cyclone, etc.) to divert the *Sargassum*.

If the barrier is used in an exposed location, it may be better to use the Goeland 300NM model.

TABLEAU SYNOPTIQUE / SYNOPTIC TABLE

DÉFINITION DEFINITION	PRODUIT PRODUCT	INTERVENTION INTERVENTION	PERMANENT PERMANENT	HAUTE MER OPEN SEA	LITTORAL COTIER COASTAL LITTORAL	PORTUAIRE PORTUAIRE	FLUVIAL BIG RIVER	RIVIERE RIVER	LAC LAKE	ROCHEUX ROCK	SABLEUX SANDY	HOULE CLAPOT SWELL CLAPOT	VENT WIND	COURANT DE SURFACE SURFACE CURRENT	FORCE FORCE	TOURET REEL	CONTENEUR CONTAINER	VOLUME M3/ML VOLUME M3/ML	POIDS KG/ML WEIGHT KG/MLA
MOUSSE PLATE - PLATE FOAM	BARRACUDA 100 S	O	PR			xxxx			xxx		xxx			xx	x	xxx	xxxx	0,018	3.1
	BARRACUDA 200 S	O	PR			xxxx			xxx		xxx			xx	x	xxx	xxxx	0,026	3.4
	BARRACUDA 300 S	O	PR			xxxx			xxx		xxx			xx	x	xxx	xxxx	0,039	4.9
	BARRACUDA 150	O	PR			xxxx	x	xxx	xxx	xx	xxxx	x	x	xxx	x	xxx	xxxx	0,026	4,3
	BARRACUDA 200	O	PR			xxxx	x	xxx	xxx	xx	xxxx	x	x	xxx	x	xxx	xxxx	0,032	4,6
	BARRACUDA 300	O	PR		xx	xxxx	x	xx	xxx	xx	xxxx	xxx	xx	xx	xx	xxx	xxxx	0,039	4,9
	BARRACUDA 420	O	PR		xx	xxxx	x	x	xxx	xx	xxxx	xxx	xxx	xx	xx	xxx	xxxx	0,054	7,7
MOUSSE CYLINDRIQUE CYLINDRICAL FOAM	GOELAND 100	O	R				x	xxxx	xx	xx	xxxx	x	xxxx	xxx	x		xxx	0,021	2,8
	GOELAND 150	O	R				x	xxxx	xxx	xx	xxxx	x	xxxx	xxx	x		xxx	0,036	3,2
	GOELAND 200	O	R			xx	xx	xxxx	xxx	xx	xxxx	x	xxxx	xxx	x		xxx	0,055	3,7
	GOELAND 250	PR	R		x	xxx	xxx	xxxx	xxxx	xx	xxxx	xx	xxxx	xxx	x		xx	0,069	4,1
	GOELAND 300	N	R		xx	xxxx	xxxx	xx	xxxx	xx	xxxx	xxx	xxxx	xxxx	xx		xx	0,1	6
	GOELAND 300NM	N	R		xxx	xxxx	xxxx	xxx	xxxx	xxx	xxxx	xxxx	xxxx	xxxx	xx	xxx	xx	0,1	6
	GOELAND 400	N	R		xx	xxxx	xxxx	x	xxxx	xx	xxxx	xxx	xxxx	xxxx	xx		xx	0,176	7,2

O : Oui N : Non R : Recommandé PR : Pas recommandé x : Faible xx : Moyen xxx : Bon xxxx : Excellent

O : Yes N : No R : Recomanded PR : Not recomanded x : Low xx : Middle xxx : Good xxxx : Excellent

Figure 20: Extract from the RCY barrier products overview (source: Catalogue RCY 2015).

The costs shown below are from the manufacturer and **are for reference purposes only**:

- Cost of the floating barrier (excluding anchoring, installation and transport): approx. €32/ml.

Key points to note

RCY barriers have several key advantages:

- **A barrier produced on an industrial scale** that can be ordered in large volumes.
- A relatively cheap barrier to buy, excluding anchors and installation (approx. €32 m/l).
- **Maintenance-friendly** due to the type of skirt which just requires brushing.
- **A barrier comprising 25 m easy to install and replaceable modules**, cutting removal and reassembly times in bad weather.

That said, initial feedback indicates that this type of barrier is not effective at containing seaweed in areas exposed to swells or strong currents. As the skirt is solid, it must be relatively short to reduce surface area drag in the water.

This type of barrier seems better suited to more sheltered areas (Trou à Cyclone, ends of bays, etc.) to divert the seaweed.

4.1.2.3 Anti-*Sargassum* barrier at Saint François (Guadeloupe)

The anti-*Sargassum* barrier installed at Saint François by the STOP SARGASSE Association is a handmade barrier set up in 2018 around the marina. Two visits were conducted on 6 and 23 June 2018, while additional inspections were planned during the 2018 hurricane season.

Figure 21: View of the STOP SARGASSE Association cubi block barrier

The barrier comprises:

- Modular floats: The blocks are recovered materials from a swimming pool stored in the municipal sports stadium.
- A 0.80 m skirt under the barrier made of 50 mm diameter textile net. The skirt is attached to the floats by steel bars positioned every four modules (one module contains 2 cubi blocks) and directly hooked to loops on the blocks.
- The barrier is anchored every 20 m. The chain is directly attached to the loops on the cubic blocks

Figure 22: View of a module (left) and the connection between two modules (right).

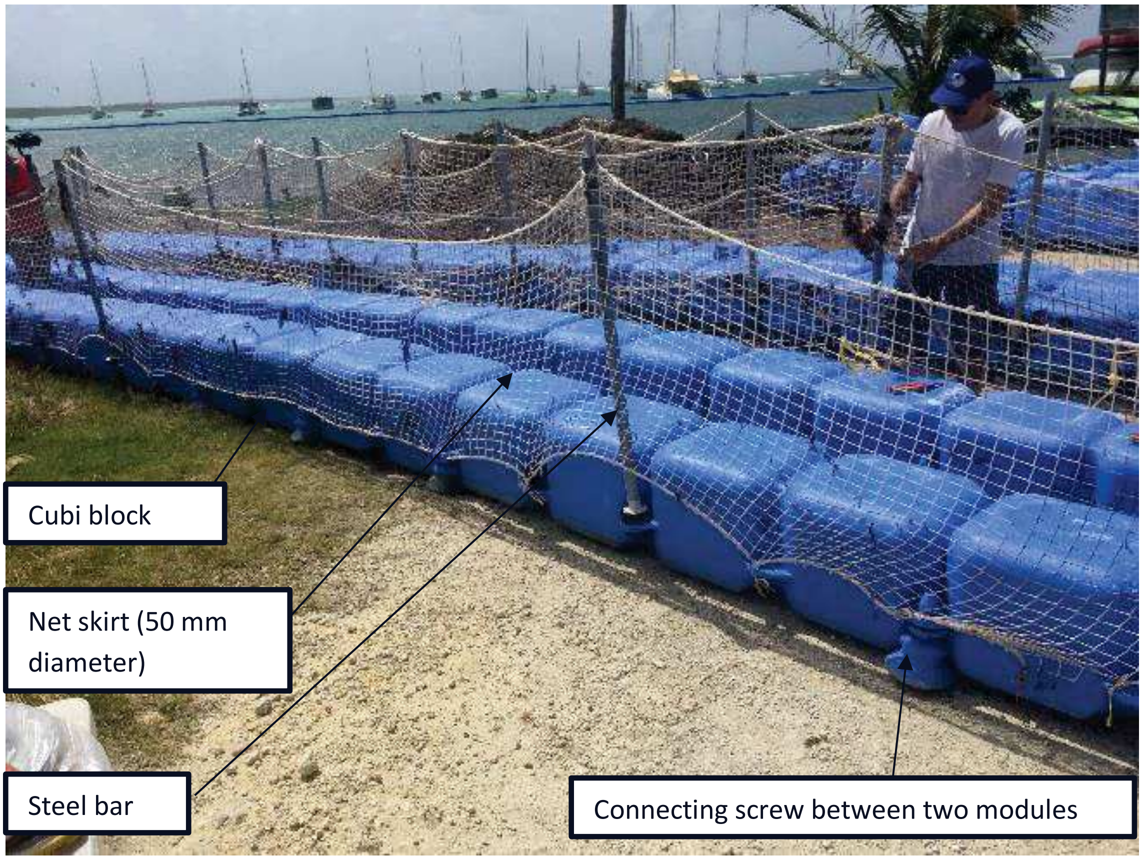


Figure 23: View of a barrier being assembled

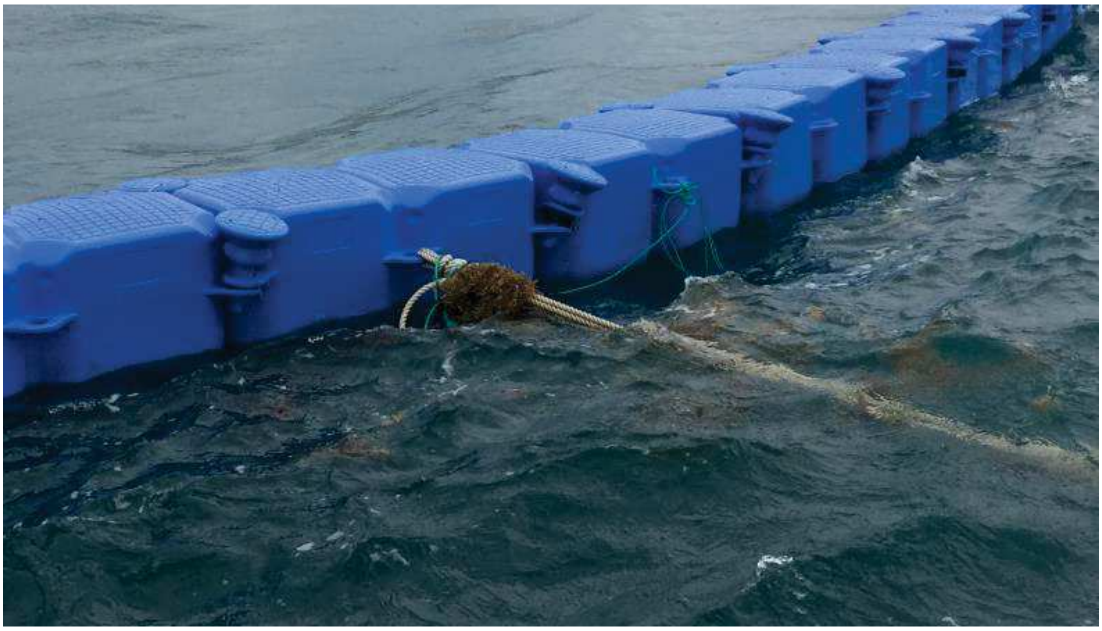


Figure 24: View of barrier anchor point

Figure 25: View of the start of the barrier

No technical details for the cubi blocks were provided. They are most likely blocks imported from Australia or Asia (a budget version of CUBI® blocks)

As the material was made from recovered materials not currently used, we cannot provide a cost for this specific barrier.

For information, the cost of a budget CUBI® block model is approximately €105/ml, excluding anchoring and nets.

Key points to note

At the time of writing, little feedback is available on the use of this type of 'handmade' barrier. During the two inspection visits, the barrier was functioning properly but had just been installed in a sheltered area. Additional visits will be made over the next few months to evaluate changes to the barrier and any problems encountered.

This type of barrier has the following advantages:

- It is made of recovered and recycled parts that are easily available. The cubi floats are specifically designed for use in the sea (floating pontoons, tidal swimming pools, etc.).
- The net skirt helps reduce the pressure exerted on the barrier from currents. The height of the skirt also helps contain thick layers of sargassum seaweed.
- The 50 mm diameter netting cuts the risk of species such as sea turtles getting stuck in the net (source: *Guidelines to cut sea turtle mortality rates in fishing operations. Rome, FAO 2013. 132 p*);

There are however several points to note:

- **Questionable sturdiness of the barrier to the force of the sea and wear and tear.** Technical characteristics of the blocks are unknown. For information, the anchoring loops attached to CUBI® blocks have a tensile strength of up to 3 tonnes before breaking in this set-up. In this particular case, the breakage threshold is probably less and could possibly be exceeded at the attachment points for the anchor lines or the steel bar mounts that hold the net in place if the barrier is beached or subjected to strong currents. The barrier's current location in a sheltered area (marina) means that this aspect cannot be properly assessed.
- **Net maintenance arrangements unclear.** Once at sea, the net will be gradually colonised by seaweed, molluscs and crustaceans. This colonisation will ultimately impact performance (weight, wear and tear, net mesh clogged up and rising pressures exerted by currents, etc.). The net skirt must therefore be cleaned regularly. Currently, the net is only cleaned by hand in the water or by pulling it on to the beach.
- **Storage capacity required on land?** The materials comprising this barrier cannot be compressed and take up a lot of space (floats, steel bars, etc.), so the barrier must have a sufficiently large area to assemble it, maintain it and store it in inclement weather.

4.1.2.4 Handmade mesh barrier at Robert (Martinique)

The municipality has installed anti-*Sargassum* barriers in the Baie de Robert.

These barriers are improvised and were installed in June to July 2018.

An inspection was made on 7 August 2018 with representatives from ADEME, the marine nature park and the Department of Maritime Affairs.

Figure 26: View of the improvised barriers installed in the Baie du Robert.

These barriers are made of:

- steel bars driven into the seafloor to anchor the barrier skirt;
- a plastic mesh skirt, attached to the steel bars by two ropes entwined in the mesh of the net on the top and bottom of the barrier with cable ties;
- and occasionally, polystyrene blocks used as floats.

Figure 27: Improvised barrier attachments in the Baie du Robert

Figure 28: Polystyrene blocks installed in the Baie du Robert.

Several faults were recorded during the inspection visit:

- The fixed position of the skirt means it does not rise and fall with the tide. A lot of debris was seen on top of the barrier (see Figure 26) emphasising the fact that, at high tide, or a large swell, seaweed could pass over the top of the barrier. The skirt was also visibly drooping in various places. As such, the barrier was not working properly.

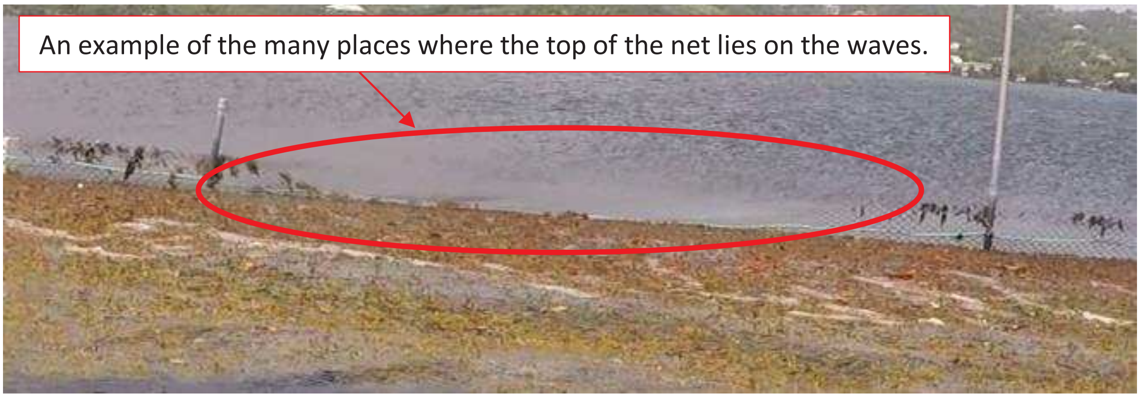


Figure 29: Skirt drooping on one of the improvised barriers installed in the Baie du Robert.

- There was a marked lean to part of the steel anchoring bars due to the considerable pressure from the sea. Once tilted over, the steel bars do not return to their original position naturally, thereby preventing the barrier from operating properly.
- At certain points, the barrier had actually split.

Figure 30: Torn mesh skirt on an improvised barrier installed in the Baie du Robert.

Key points to note

At the moment, the improvised mesh barriers installed in Robert display serious structural weaknesses (numerous flaws observed in different sections). If a swell develops, the barrier cannot retain seaweed as it will pass over the top of the booms.

As such, the question of just how robust these barriers are in extreme conditions is a serious concern. Their fixed, non-modular structure means these barriers cannot be quickly removed and reassembled. Currently, the net and attachments must be cut free (cable ties, rope, etc.) to remove them, which requires additional repair work when reinstalling the barrier.

These barriers do not appear designed to resist strong swells and even less, cyclonic swells. The additional costs for repairs and replacement parts, together with the pollution caused (polystyrene, plastic nets) will quickly become a problem.

The barriers do not seem to be adequately maintained.

It should be noted that these evaluations prevent us drawing conclusions about all existing net mesh barriers, given the various materials and installation techniques used, as well as sea conditions at each site. Feedback on the use of these barriers is still scarce.

4.1.2.5 Improvised mesh barrier at the Anse Bertrand (Guadeloupe)

The SDIS has installed an improvised anti-*Sargassum* barrier at the Anse Bertrand, in Guadeloupe. This barrier comprises the following parts

- Boat fenders to help the barrier float and maintain the skirt in position (protection against floating debris).
- A 0.50 m skirt under the barrier made of a textile net 25 x 25 mm diameter mesh.
- Anchoring points every 3 m (240 kg mooring buoys) with an approximately 20 mm diameter chain connecting the anchoring to the barrier.

Figure 31: Improvised barrier at Anse Bertrand.

At the time of the inspection, the barrier was incomplete due to component supply problems.

It was noted that some of the *Sargassum* passed over the barrier as the ridgeline was irregular in places.

SDIS estimated the cost of installing this barrier at €12,000 for 64 ml, i.e. approximately €187/ml. **The barrier failed after 3 weeks and was not reinstalled**.

Key points to note

The barrier breaking after being in place for such a short time illustrates the difficulties to install and maintain this type of method and the limits of improvised techniques in areas with sea swell and strong currents.
Overspilling sargassum observed during the period it was in use shows the need to keep the net raised at a uniform height above the waterline for the barrier to work properly.

4.1.2.6 Mesh barrier at Frégate Est 2 and Cap-Est (FILET DROM)

FILET DROM installed two anti-*Sargassum* barriers with private financing at Frégate Est 2 in the municipality of François:

- A 300 m-long barrier at Frégate Est 2 was installed in June 2018 and inspected on 7 September 2018 with ADEME. The site was relatively sheltered from swells. The depth is shallow along the whole barrier length (0.5 to 1.5 m).

Figure 32: The improvised barrier at Frégate Est 2 (June 2018).

- A 2,700 m-long barrier at Cap Est was installed in February 2019 and inspected in August 2019.

Figure 33: The improvised barrier at Cap Est (August 2019).

These barriers have a similar design and comprise:

- Polystyrene blocks every 1.5 m as floats, which are gradually being replaced with patented plastic buoys.
- A skirt made of rigid plastic mesh made of parts all stitched together. The net mesh is 5cm in size and varies from 1 to 2 m-long, with 0.2 m above the water. The mesh is held down at the base by a rope with lead weights or an iron bar in parts of the barrier where the backwash of the surf or currents are the strongest. The barrier is anchored by two ropes fed through the mesh on the top and bottom of the barrier.
- Ballast, in the form of weighted ropes or steel bars attached at various points to the bottom of the barrier.
- 55 kg anchors tether the barrier, either single or doubled-up according to sections along its length. The anchors are attached to the mesh by wood floats. A more supple, flexible mesh provides a link between the wood floats and the main mesh skirt, to ensure the barrier has some give at the anchor points.

Figure 34: Underwater view of the barrier at Cap-Est during the inspection (08/2019)

Figure 35: The improvised barrier at Frégate Est 2 at the time of the inspection (07/09/2018)

The barrier was set up to form pockets to hold the *Sargassum* on the surface. It is not designed to divert the mats of seaweed but rather confine them.

4.1.2.6.1 Observations on the barrier located at Frégate Est 2

No obvious wear and tear on the barrier skirt, despite poor visibility.

The skirts sits straight over the whole barrier length and showed no sign of drooping or colonisation by sedentary organisms. The lack of colonisation is potentially due to poor water quality over the whole site (light, physical and chemical properties, etc.), as it had a poor record of sizeable uncollected strandings until June-July 2018.

No signs of life could be observed and several dead fish were visible in the mat of *Sargassum* held by the barrier.

The polystyrene floats were still in place but most were starting to visibly deteriorate:

Figure 36: Comparison between the state of floats in June 2018 (left) and September 2018 (right)

Discussions with local residents revealed that the barrier traps mats of *Sargassum* on the surface and retains them. Comments indicated that the trapped *Sargassum* sinks after a few days (4-5 days based on local estimates).

During the site visit, **no clumps of rotting seaweed were observed on the sea floor, straight in front of the barrier, under the holding area**. Some knots of seaweed lying on the sea floor were however recorded in the protected area. This tends to confirm the assumption that once blocked by the barrier, the seaweed sinks where it is a few days later and is then moved by bottom currents. At least part of it then gradually moves under the barrier to wash up on the shore and carry on decomposing.

Indeed, despite several *Sargassum* clean-ups in June and July 2018, and the barrier remaining in position, new strandings were still present. It is not possible to estimate what proportion of the *Sargassum* on the shore had previously been trapped by the barrier.

Figure 37: The shoreline between June and September 2018

When Tropical Storm Isaac passed through on 13-14 September 2018, the supplier removed the floats from the barrier to protect it and leave the mesh net to sink to the seafloor by cutting the fixings. It took 4 hours and 3 people to submerge the 300 m section left. It also took several days (estimate) to put the barrier back in place. **The time taken to reinstall the barrier can be a major drawback when it covers long lengths** (coastline left unprotected, labour required and related costs) **and must be reduced**. Changes to the system of connecting the floats, making it easier to remove and replace them by shackles and snap-hooks, etc., fewer floats or a different protection method, should all be studied.

At this stage, there is not enough feedback on sinking the net to judge whether this method is actually effective or not. The system does however raise several questions:

- What is the risk that the mesh net gets damaged once on the seabed?
- What are the difficulties related to putting it back in place, in relation to its weight, length and bathymetry?

4.1.2.6.2 Observations on the barrier located at Cap Est

At the time of the inspection, 6 months after it was installed, the barrier was generally in a good state, although the skirt was partially colonised by seaweed and molluscs in some sections. The barrier stayed upright and showed no signs of drooping. The seaweed present was properly confined by the barrier.

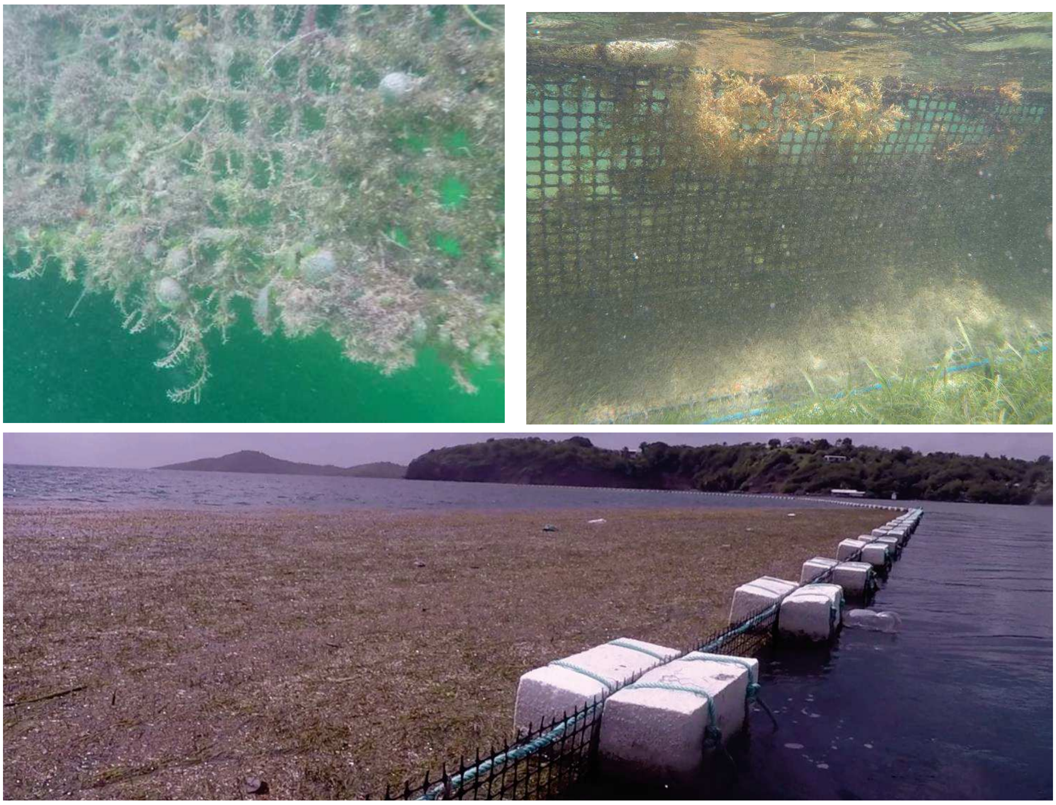


Figure 38: The barrier at Cap Est, top left: Skirt being colonised (August 2019)

According to discussions with the manufacturer, the barrier undergoes regular maintenance (3-4 times a year). The total cost of the barrier is approximately €350,000 for 2.7 km, i.e.€130/ml. Annual maintenance costs are estimated by the manufacturer to be 18% of the total cost per year (i.e. approximately €23.4 per year per ml).

Some of the polystyrene floats were being replaced by patented plastic floats.

Figure 39: New anticipated floats

During discussions, one reason for wear and tear of the barrier that required significant repair work was linked to boats not always keeping to the channels.

Key points to note

At this stage, apart from the polystyrene block floats already showing signs of wear and tear, the barrier installed at Frégate Est 2 does not seem to show any signs of deterioration, despite the poor visibility. These are currently being replaced by more robust moulded plastic floats.

The barrier is positioned to prevent floating mats of sargassum washing up on the shore and works properly.

Part of the seaweed appears to pass under the barrier once it sinks when not collected beforehand. The proportion of sargassum reaching the shore could not be assessed. The phenomenon is not unique to this type of barrier.

In the event of a weather warning, the supplier can protect the barrier by disconnecting the floats and leaving the mesh net to sink to the seafloor. However, when a weather warning was issued, it took 4 hours for the 300m barrier at Frégate Est 2 to submerge and required 3 people. It also took several days (estimate) to put the barrier back in place. **The time taken to reinstall the barrier can be a major drawback when it covers long lengths (coastline left unprotected, labour required and related costs) and must be reduced.**

The skirt on the barrier at Cap Est was visibly colonised. Conversely, the barrier at Frégate Est 2 was untouched, probably due to the poor water quality at this site, severely affected by sargassum strandings.

4.1.3 Review of the barriers

Currently, given local feedback, the **use of barriers to divert and concentrate *Sargassum* in predefined areas** in order to remove and/or manage it seems to be **the most appropriate solution**.

Indeed, if the *Sargassum* is not harvested from barriers designed to store it at sea, the seaweed ends up rotting and sinking to be dispersed by bottom currents. Consequently, it can still find its way to supposedly protected shorelines and release H2S. The use of containment or blocking barriers depends on the layout of the site, especially good water circulation. Without adequate water circulation, the barrier could be counterproductive. Regular collections also help to restrict these effects and prevent *Sargassum* passing underneath the barrier (or mounting pressure from the seaweed causes the barrier to break).

Using barriers requires:

- The ability to **quickly install and remove** long booms with proportionate means. Indeed, if a weather warning is issued (swell, winds, etc.), the resistance of the barriers may be compromised according to the materials used and their locations. In addition, when a weather warning has been issued, the means to handle and shift the barriers must be available (managing priorities in the whole area).

  Wear and tear to the barrier leads to:
  - Extra costs to repair damaged components.
  - Longer periods when supposedly protected sites are at greater risk of *Sargassum* strandings.
  - A pollution risk for the surrounding environment if parts are lost (plastics, foam, etc.).
- The **ability to maintain the barrier** to ensure the equipment lasts as long as possible, especially assuming long lengths of barriers are installed includes:
  - Removal of floating debris that could damage the skirts and floats.
  - Cleaning barrier components once colonised by sedentary organisms.

These deliberations make the case for:

- The use of modular section barriers to gain greater flexibility in the attachments and, if a section is damaged, to replace just that section without having to 'patch it up'.
- The use of deflatable (inner tubes) or compactable (foam) booms or floats can also help save storage space compared to rigid components. This aspect is especially relevant when importing materials (less containers needed) or removing the barrier when rough seas are forecast, with the option of storing longer lengths on small boats.
- Developing robust, low-maintenance technology.
- Introducing emergency action plans to remove barriers.
- Using barriers fitted with floats that rise and fall with tides or waves to prevent them from being submerged.
- Developing appropriate collection methods close the shoreline.

The positioning of a barrier depends on many parameters that must be studied in advance. These include currents, normal agitation on the water surface, moorings (land-to-sea cables), uses (maintaining a passage for boats and other users, etc.). The type of anchoring system depends on the substrate, the tides and how agitated is the water.

4.2 Collection methods

4.2.1 Generalities

4.2.1.1 Collection and disposal cycles

Sargassum removal tasks, whether they be manual, mechanised, onshore or offshore, can be split into two cycles, each with different stages systematically found in each method:

- **An on-site collection cycle** comprising:
  - A collection period for the *Sargassum* stranding/mat: This is specific to the harvesting method used and can vary based on the type and density of the stranding. It will be used to identify the **unadulterated harvesting yield**.
  - Travel time from the *Sargassum* stranding/mat to the disposal point for harvested seaweed. This time varies for the same method used depending on distance between the stranding/mat and the disposal point (tipper truck, piles on the ground, etc.).
  - The time to empty the harvested material. This time is specific to the collection method used and is not supposed to vary significantly.
  - Travel time from the emptying point to the *Sargassum* stranding/mat. This time varies for the same method used depending on distance between the stranding/mat and the disposal point (tipper truck, piles on the ground, etc.).

  The duration of a cycle can be used to estimate an **overall hourly collection yield**.

- **A disposal cycle** when seaweed has been put placed in a tipper truck, which corresponds to the time taken by the hauliers to empty the truck and return to the site. This time is independent of the harvesting method but can strongly influence daily collection yields when having a tipper truck is vital to the collection site. It should be noted that this cycle does not always feature when harvested seaweed is all piled together on one site. A period of time for the seaweed to dry out can reduce the volume for transport (drying and compacting) and cut the number of rotations needed.

For each of the methods featured below, we are mostly interested in the collection cycle as this is specific to the methods tested.

A table summarising the data and a decision tree are given in section 4.4

4.2.1.2 Points to note about clean-up operations

Clean-up operations can have numerous implications for public health and the environment. The main points to note for a collection operations concern:

- **Operator safety**: CEVA has published a leaflet summarising the necessary equipment and operational rules in seaweed stranding areas. The leaflet is appended to this report. A summary is presented below:
  - For open-air collections, operators must wear **protective equipment**:
    - Personal Protective Equipment (PPE): boots, gloves, overalls and lifejacket, etc.
    - H_2S detector for all workers likely to be exposed to the gas. These devices must be worn close to the nose or mouth and feature the following characteristics:

H2S detector features

A Atmospheric H2S levels permanently displayed

B Two visual and audible alarm limits :

- *Alarm 1*: 5 ppm or 7 mg/m3
- *Alarm 2*: 10 ppm or 14 mg/m3

C Fitted with a sufficiently large memory to record:

- The anomalies/incidents logbook with corresponding date and time.
- Operator exposure readings set to be taken approximately every 30 seconds.
- Exposure readings over a minimum period of 15 days.

D Option to connect the detector to a computer to recover and process recorded data.

- This data helps, in particular, to monitor gas exposure rates for each person

Figure 40: H2S gas detector features (source: CEVA, intervention checklists)

- Respiratory protection devices:
  - For fresh seaweed strandings (source: CEVA): half-face mask complying with French standard NF EN 140, with A2B2E2K1 filters designed according to French standard NF EN 14387. Respiratory protection devices must be worn as soon as the gas detector emits a signal indicating a danger.
  - For older seaweed strandings (source: CEVA): Power air purifying hood meeting minimum category standard TH2, designed in compliance with French standard NF EN 12941 and fitted with TH2 A2B2E2K1 filters, or a SCBR, self-contained compressed air breathing apparatus for decomposing seaweed in an advanced state. **This type of apparatus is for services and individuals specialising in high-risk clearing operations**.

Respiratory protection devices must be worn as soon as the gas detector emits a signal indicating a danger (5 ppm: Do not remain more than 15 min in the area), including situations requiring the work area to be cleared (10 ppm). (Source: CEVA

Dust mask filters offer no protection against H_2S.

- In the event of clearing operations in a pressurised cabin:
  - H_2S detector and respiratory protection (see above)
  - For biological gas-dust treatment (dust and active carbon filter)

- **<u>On-site mobility</u>**. Collection methods can be hampered by:
  - Onshore:
    - Beach load bearing capacity: Risk of getting stuck in the sand and material stranded when the beach cannot bear the weight of heavy machinery.

Figure 41: Tractor trapped in the sand during a clean-up operation (Anse Azérot, Martinique)

Since the first trials, the load-bearing capacity of many beaches has gradually declined due to repeated clearing operations:

- *Erosion linked to highly invasive heavy machinery clean-up methods (long-reach excavators, diggers, etc.).*
- *Combined strandings of uncollected seaweed rotting in large quantities and mixing with the sand to reduce load bearing properties.*

Without measures to offset this gradual deterioration, the number of clean-up operations and mechanised collection methods will have to be cut back.

    - Restricted width for vehicles: Some sites can be too narrow for vehicles or require access and turning areas to be built.
    - The size of the stranding precludes some methods in the case of vehicle movements on thick mats of seaweed.
  - Offshore:
    - Poor weather conditions (swell, currents) can disadvantage harvesting machinery.
    - Bathymetry can restrict the area used by machinery.
    - Coastal access can restrict the area to launch or anchor machinery and, as such, affect the time taken to reach the harvesting area.
- **Environmental impacts**:
  - Onshore:
    - **Beach erosion**: Beach clean-ups can also remove varying amounts of sand, which ultimately leads to:
      - The beach gradually disappearing and impacting uses (swimming, etc.).
      - Reduced load bearing capacity: Increasingly complex access for collection machinery and constraints on vehicle movements, with some areas becoming inaccessible.
      - Greater surface area exposed to seaweed strandings.
      - Coastlines increasingly vulnerable to erosion from swells.
      - Less space available for sea turtles to lay their eggs.

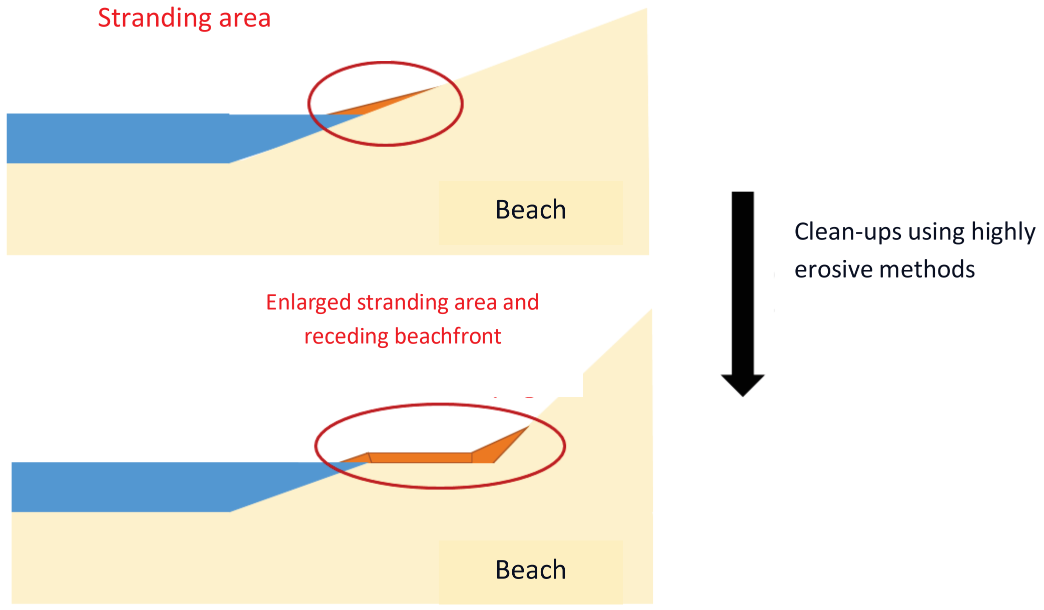


Figure 42: Diagram showing how the beach changes after seaweed clean-ups using highly erosive methods

Figure 43: Piles of sand from mechanised *Sargassum* beach clean-ups (Dominican Republic)

Given the potential for erosion, it seems wise to:
- *Keep the most aggressive collection methods to a minimum.*
- *Separate and identify deposits according to their original beaches (preserving sand with the same physical characteristics).*
- *Return sand to its original location, respecting 'beach nourishment' guidelines.*

- **Rut formation** that could trap young sea turtles once hatched[6], or areas where seaweed collects. This effect can be seen at sites with low load bearing capacities.

Figure 44: A 30 cm rut formed after the passage of a tractor (Anse Azérot, Martinique)

- **Risk of crushing sea turtle nests**. Sea turtles, their eggs and nest sites are fully protected by Ministerial decree of 14 October 2005. Vehicle movements must be controlled outside egg-laying periods (on the upper beach) by installing markers and restricting traffic in high-risk areas (turning areas and beach access points). Machinery that spreads its weight on the ground and manual removal are preferable.

Points to note

DEAL French Guiana has published a guidelines for seaweed collections at sea turtle nesting sites (see APPENDIX), while the ONCFS and the Guadeloupe sea turtle network have also published recommendations on the matter (see APPENDIX).

[6] Hosier, P.E., M. Kochlar, and V. Thayer. 1981. Off-road vehicle and pedestrian track effects on the sea approach of loggerhead turtles. Environmental Conservation 8 :158-161.

- **Maintaining debris lines**: Onshore beach clean-ups must not remove all seaweed present as, in reasonable quantities, it does play a positive role on the shoreline, such as protection against erosion, shelter and food source for many species.

Figure 45: Collection limits (source photo: DEAL Martinique, "Sargassum *strandings in Martinique – environmental impact* ")

- Offshore: Trapped aquatic wildlife

- **Equipment maintenance** : *Sargassum* is collected in an dynamic environment (water, salt, sand, H_2S) that has a degradative effect on many items of equipment. It is therefore vital to properly maintain materials to ensure they last as long as possible. Systematically rinsing equipment in fresh water after each use, coupled with regularly greasing delicate components (according to suppliers' guidelines) is a bare minimum and requires some basic equipment (water supply) near to the collection areas.

4.2.2 Mechanised offshore collection

Table2: Summary of methods observed

Categories	Organisations	Tools
Mechanised offshore collection	ALGEA NOVA	Harvesting barge
	SEREG / Robert Municipality	Small harvesting barge
	SGM	Amphibious vehicle and pumping system
	SLTM	Crane operation
	ELBE	Trailing suction hopper dredger
	SOTRADOM	Offshore harvester
		Harvesting conveyor

4.2.2.1 Offshore harvesting barge – ALGEANOVA

ALGEANOVA carried out some offshore harvesting operations using a prototype barge, which was inspected in the Dominican Republic, in May 2018.

4.2.2.1.1 Labour requirements

During the inspections, staff present included:

- A captain,
- A crane operator,
- 2 to 3 workers.

4.2.2.1.2 Equipment requirements

The harvesting barge used by ALGEANOVA is a prototype motorised vessel which harvests *Sargassum* mats offshore (close to the coast) on a tilted conveyor belt as the barge moves through the water. The seaweed is then stored in 1.5 m3 big bags at the rear of the vessel. It can hold up to 35 big bags, i.e. 52 m3 (approx. 15-20 tonnes).

Figure 46: Prototype harvesting barge used by ALGEANOVA

The main features are shown below (manufacturer's data):

- Speed in transit: approx. 5-7 knots;
- Harvesting speed: approx. 2 knots;
- Belt collection width: 6m
- Operating depth: Adaptable from 0 to 30 cm;
- Storage capacity: 45 - 60 m3 (approx. 15-20 tonnes);
- Draft, barge empty: 1 m;
- Draft, barge full: 1.5 m.

The barge is also equipped with a mini-crane to move the big bags around the barge and offload them (capacity: 500 kg at 4 m).

Figure 47 : Big bags stored on board and being moved

4.2.2.1.3 Seaweed collection arrangements

Collection arrangements are described in section 4.2.1.1, p50.

4.2.2.1.4 Estimated yield

There are two estimated yields:

- Unadulterated collection yield, not including limitations due to storage volumes, transit and disposal times.
- Overall yield, including limitations due to storage volume, transit and disposal times.

The collection yield has been calculated according to time taken to fill 53 1.5 m^3 big bags, taking into account the density of the seaweed mat collected and its thickness (H) (visual estimate).

- Low density: The mat does not cover the whole surface (H: approx. 0.1 m).
- Medium density: the mat almost covers all the surface (H: approx. 0.1 - 0.2 m).
- High density: The mat covers the whole surface (H: > 0.2 m).

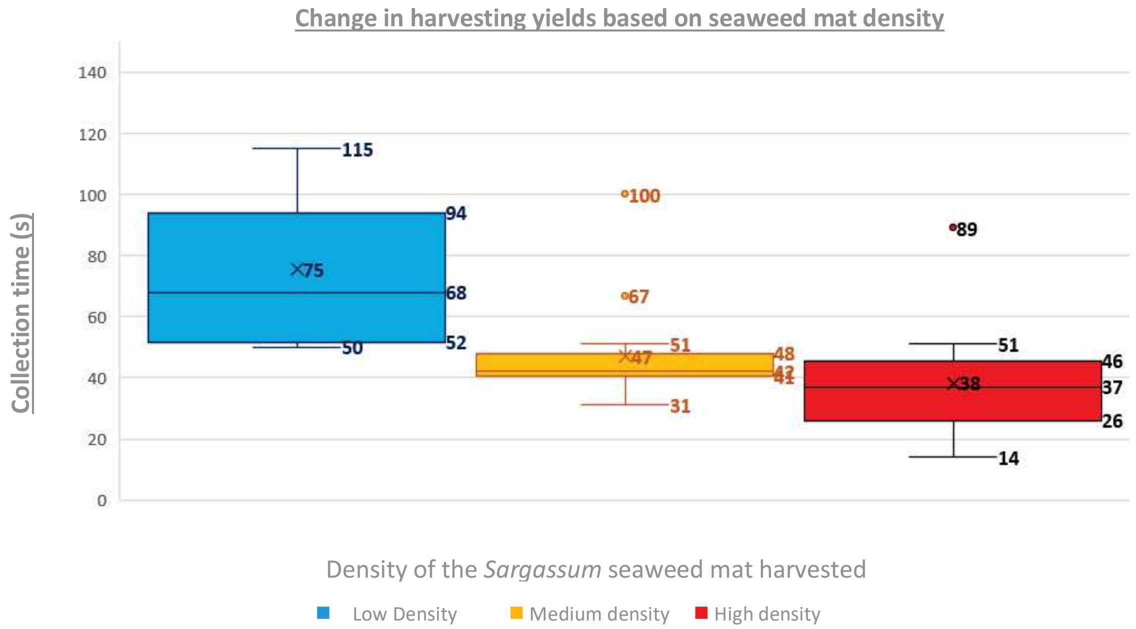


Figure 48 : Changes in 1.5 m³ big bag filling rates

It was observed on-site that average filling time varies according to the density of the seaweed mat.

- Low density: 75 seconds, **or 72 m³/h**.
- Medium density: 47 seconds, **or 115 m³/h**.
- High density: 38 seconds, **or 142 m³/h**.

In optimal user conditions, (medium to high density), the unadulterated collection rate is between 115 and 140 m³/h.

The overall yield features a fixed component (harvesting and emptying times) and a variable factor (journey times depending on the distance between harvesting and emptying points).

- The average collection time observed to harvest 30 big bags was 33 min, or 83 m^3/h.
- The average time to empty a big bag was 82 seconds, or 41 min for 30 big bags.

As such, the fixed component of the overall yield for 30 big bags (45 m^3) is 1 hour and 15 min or approx. 35 m^3/h

During the tests, the travel time between the harvesting and disposal points was 15 min, or a 30 min round trip, resulting in an overall yield of 45 m^3/1 hour 45 min, or **25-30 m^3/h.**

Assuming four collection cycles a day, the prototype can harvest approximately 180 m^3 of *Sargassum* per day, or roughly 60-70 tonnes of fresh drained seaweed (approx. 300 kg/m^3).

Key points to note

The unadulterated collection yield is high (70-140 m^3/h) but severely compromised by the offloading time from the barge (approx. 1.2min/big bag) and transit time between the seaweed mat and the disposal point. Assuming four collection cycles a day, the prototype can harvest approximately 180 m^3 of sargassum per day.

4.2.2.1.5 Costs

At the present time, ALGEANOVA has no plans to lease the prototype on a daily basis but intends introducing an annual maintenance contract, including installation of the floating barrier, maintenance and collecting seaweed along the length of the barrier using the barge. As this is a prototype version, the model that will eventually be marketed will be new (version 2) and cost roughly €980,000 before tax.

4.2.2.1.6 Strengths and weaknesses

Type of impact	Comments	
Yield	Using a sloping conveyor belt to harvest the seaweed results in a yield ranging from 70 to 140 m^3/h but this is compromised by significant periods of time for barge movements and emptying. Assuming four collection cycles a day, the prototype can harvest approximately 180 m^3 of *Sargassum* per day.	
Suction width	6 m width to harvest seaweed over a wide area.	-
Collection area	Close to shoreline	
Fresh seaweed clean-up capacity (<48h)	Very good.	
Old seaweed clean-up capacity (>48h)	Fairly good A test conducted on old *Sargassum* seaweed caused the conveyor belt to temporarily jam as the rotting seaweed mat was more compact.	
Effect on beach erosion	Offshore harvesting helps protect against erosion processes	
Beach load bearing capacity (formation of ruts, bogging down)	n/a	
Impacts on marine wildlife	n/a	
Mobility	During trials, the harvesting barge demonstrated good manoeuvrability to easily position itself for harvesting the seaweed (forwards, backwards, turns). Its shallow draft means it can operate close to the shoreline.	
Workers' health and safety	The team works in the open air and, as such, can be directly faced with: o H_2S risks; o Odour nuisances. o Weather conditions (sun, rain). However, as the seaweed is harvested offshore, the effects are less serious than on land due to wind direction and less seaweed rotting in the water.	

4.2.2.1.7 Areas for improvement

The barge is a prototype and the main areas for improvement identified during trial include:

- **Conveyor belt operations**: Widening the conveyor belt mouth to 9 m and reducing the number of belts will raise collection yields, enable the barge to harvest seaweed along a floating barrier in one sweep and significantly cut the jamming problems where two conveyor belts meet.
- **Increasing the size of the big bags** to 3 t (approx. 6.5 m^3): This bigger size will significantly reduce emptying times using the crane.
- **Introducing 30 t mobile storage hoppers**, separate from the harvesting barge. Once filled, these storage hoppers can be uncoupled from the harvesting barge and taken to the disposal point. A second unit can then take the place of the first and the collection can continue. This innovation means that the barge could remain in the harvesting area for the entire time it is used (10 to 12 hours) and the number of storage units geared to the distance to be covered and the seaweed mat density.

It may also be possible to improve the efficiency of these barges outside *Sargassum* stranding events by developing tools designed for other marine operations (dredging, installing floating barriers, etc.).

4.2.2.1.8 Conclusions

Key points to note

This pick-up barge is a prototype offshore mechanised harvester (close to the shoreline).

It achieves an overall yield of approximately 30 m^3/h for dense seaweed strandings close to a disposal point (figure recorded for a one-way journey of about 2 km).

This yield could be improved but remains restricted by
- *The speed the barge can travel at.*
- *Barge storage capacity.*
- *Barge emptying time.*

The system ensures sargassum strandings have no adverse effect on the coastline.

***For optimal operating conditions, this method must be combined with a seaweed concentrator system (floating barrier)** to gather the seaweed together in an area with sufficient draft and, in doing so, reduce the surface area to be cleared offshore.*

4.2.2.2 Small conveyor belt pick-up barges - SEREG company, Robert municipality

SEREG has undertaken mechanical offshore harvesting operations using small pick-up barges in Guadeloupe and the municipality of Robert, in Martinique.

4.2.2.2.1 Labour requirements

During the inspections, staff present included:

- Offshore:
  - A captain,
  - 2 workers;
- A crane operator
  - A crane operator (this can be a crew member)
  - A tipper truck driver

4.2.2.2.2 Equipment requirements

The motorised pick-up barges are made of aluminium, with a tilting conveyor belt to harvest mats of *Sargassum* seaweed offshore (near to the coast) as the vessel moves through the water. The seaweed is then stored at the rear of the barge, either in big bags or a small hopper. Storage capacity is approximately 9 m^3.

Figure 49: Small pick-up barges used in Guadeloupe, the "Sargator" (left) and the "Lougarou" (right) in Martinique

4.2.2.2.3 Seaweed collection arrangements

Collection arrangements are described in section 4.2.1.1, p50.

Figure 50: Small pick-up barges used in Guadeloupe and Martinique

4.2.2.2.4 Estimated yield

Pick-up barge performance over a full cycle relies on numerous factors:

- C : Onboard storage capacity
- $T_{(c)}$: Collection time, corresponding to offshore harvesting time to reach storage capacity. Time varies according to seaweed mat density (shorter for dense mats).
- $T_{(t)}$: Round trip transit time, corresponding to the time the barge must travel between the emptying point and the seaweed harvesting area. This time varies according to the location of the mats of *Sargassum* seaweed. The barges move at a speed of approximately 6 knots when empty.
- $T_{(v)}$ Emptying time, corresponding to the time taken to fully empty the barge once on the shore. This time is the same from one emptying operation to another, apart from when there is no storage equipment (tipper trucks, etc.).

$$\boxed{\text{Cycle yield} = C/(T_{(c)}+T_{(t)}+T_{(v)})}$$

As a result, the yield from one cycle for each type of barge can vary considerably according to harvesting time ($T_{(c)}$), which depends on seaweed mat density and transit time ($T_{(t)}$).

Two yields have been estimated using data from the Lougarou in Martinique:

- **Unadulterated collection yield**, independent of limitations due to storage volumes, transit and emptying times.
- **Single collection cycle yield**, including limitations due to storage volumes, transit and emptying times.

The unadulterated collection yield has been calculated based on the average time taken to fill a 1.5 m³ big bag, taking into account the density of the mat of seaweed harvested and its thickness (H) (visual estimation).

- Low density: The mat does not cover the whole surface (H: approx. 0.1m).
- Medium to high density: the mat covers almost all the surface (H: approx. 0.1 - 0.2 m).

It was observed on-site that average filling time varies according to the density of the seaweed mat.

- Low density: Approx. 5 min, **or an unadulterated collection yield of 18 m³/h**.
- Medium to high density: approx. 1.5 min, **or an unadulterated collection yield of 60 m³/h**.

In optimal operating conditions (medium to high density), the unadulterated collection yield is around 60 m³/h.

The overall yield features a fixed component (harvesting and emptying times) and a variable factor (journey times depending on the distance between harvesting and emptying points).

- Average collection time recorded for low density: 30 min, or 18 m³/h.
- Average collection time recorded for low density: 9 min, or 60 m³/h.
- Average emptying time for one big bag: 2 min, or 12 min for 6 big bags.

During trials, the navigation time between the harvesting area to the emptying point was **25 min** for a round trip, resulting in an estimated yield in these conditions of:

- **8 m³/h for low density mats of seaweed**.
- **12 m³/h for average to high density mats of seaweed.**

Key points to note

The unadulterated collection yield varies considerably based on seaweed mat density (18 to 60 m³/h). The overall yield is compromised by the time required to empty the barge (approx. 2 min per big bag) and transit time between the mat of seaweed and emptying point, estimated at 8 to 12 m³/h for a 25 min round trip.

4.2.2.2.5 Strengths and weaknesses

Type of impact	Comments	
Yield	Small pick-up barges can deliver collection yields of 8 to 12 m³/h but this is compromised by lengthy emptying times and barge movements, as well as reduced on-board storage capacity.	
Suction width	Width of 1 to 2 m requiring numerous manoeuvres based on the seaweed mat pattern (free or concentrated)	 -
Collection area	Close to shoreline	
Fresh seaweed clean-up capacity (<48h)	Very good.	
Old seaweed clean-up capacity (>48h)	Not observed	
Effect on beach erosion	Offshore harvesting helps protect against erosion processes	
Beach load bearing capacity (formation of ruts, bogging down)	n/a	
Impacts on marine wildlife	n/a	
Mobility	During trials, the harvesting barge demonstrated good manoeuvrability to easily position itself for harvesting the seaweed (forwards, backwards, turns). Its shallow draft means it can operate close the shoreline.	
Workers' health and safety	The team works in the open air and, as such, can be directly faced with: o H_2S risks; o Odour nuisances. o Weather conditions (sun, rain). However, as the seaweed is harvested offshore, the effects are less serious than on land due to wind direction and less seaweed rotting in the water.	 

4.2.2.2.6 Areas for improvement

The barge is a prototype and the main areas identified for improvements during trials concern:

- **Widening the treadmill:** Adding feeder panels in front of the treadmill (as on the Sargator, in Guadeloupe) can significantly increase the 'footprint' collected and cut offshore harvesting times.
- **Fitting a single collection container:** Emptying times could be optimised by using a single container or bag. Greater weights collected will also require appropriate lifting gear on land.
- **Versatile equipment:** As stranding events occur in random volumes, the small shallow draft pick-up barges could be put to additional uses other than just collecting *Sargassum* seaweed. This would deliver a better return on investment in these types of vessels, so long as equipment was geared to these uses and secured the necessary authorisations. Uses could include harvesting water hyacinth in rivers, transporting tourists to small islands, shipping building materials for coastal construction work (installing barriers), etc.

4.2.2.2.7 Conclusions

Key points to note

Small conveyor belt barges are suitable for harvesting seaweed close to the shoreline.

This system harvests seaweed cleanly, without damaging the coastline or seabed thanks to its shallow draft and good manoeuvrability.

The system does however suffer from collection yields being highly dependent on distance between harvesting and emptying points as well as seaweed mat density. Limited onboard storage capacity also has a pronounced effect on yields.

To work at its best, thisTo optimise this method, it must be combined with a seaweed concentrating system (e.g. a floating barrier).
The number of crew members is high: 4-5 people (3 seamen, 1 crane operator and 1 tipper truck driver on land).

This type of small barge could eventually be put to other uses when there are no sargassum strandings if appropriate tools and equipment can be developed: harvesting water hyacinth in rivers, transporting tourists to small islands, shipping building materials for coastal construction work, etc. These aspects must be researched to generate a return on investment for this type of equipment.

4.2.2.3 Offshore pumping - Trailing suction hopper dredger - ELBE

The vessel, ELBE, carried out mechanical offshore harvesting operations using a trailing suction hopper dredger system for two trials in Guadeloupe on 30 and 31 May 2018.

Points to note

During both days, only a single 30 min seaweed collection test could be undertaken.

4.2.2.3.1 Labour requirements

The vessel requires a crew of 10, split into 2 teams, day and night shifts (5 people to a team).

4.2.2.3.2 Equipment requirements

A trailing suction hopper dredger (TSHD) is a self-propelled vessel used to dredge loose material (sand, gravel) for marine construction works. The dredgers are fitted with a storage hopper that can be emptied at sea or discharged on land. This type of dredging method has been tested in Guadeloupe on the vessel, ELBE.

Figure 51: The ELBE

The main features are shown below (manufacturer's data):

- Hopper capacity: 2800 m^3
- Length: 79.8 m
- Breadth: 15.2 m
- Speed: 11 knots when manoeuvring, 2.5 knots when harvesting
- Propulsion: 2 x 940 kw
- Dredging draft: 5.3 m
- Maximum dredging depth: 30 m
- Dredging pumps: 880 kw
- Suction pipe: 800 mm diameter

The suction area for the test was 4m² at an average suction rate of 1,000 m^3/h.

4.2.2.3.3 Seaweed collection arrangements

Collection arrangements are described in section 4.2.1.1, p50.

Before using the dredger, the location and estimated quantity of seaweed mats must first be identified. This proved to be an issue during the tests, with excursions made over several hours without finding any mats of seaweed.

4.2.2.3.4 Estimated yield

There are two estimated yields:

- The collection yield, independent of limitations due to storage volume, transit and emptying times.
- Overall yield, including limitations due to storage volume, transit and disposal times.

The collection yield was estimated using the suction rate and speed to fill the hopper based on the unproven assumption of 40% *Sargassum*/m^3 collected.

- Suction rate: 1,000 m^3/h
- Flow rate estimate: 40% *Sargassum*

During the test, the TSHD was active for 33 minutes, which corresponds to a water/*Sargassum* volume of 550 m^3, based on assumptions made of 220m^3 of *Sargassum*. This volume appears to be consistent with that observed in the hopper (approx. 10% of the total volume, or 280m^3 of water/*Sargassum* mix, with part of the water collected being directly returned to the sea).

The collection yield for a dense mat of *Sargassum* (average visually estimated height of 0.3 m) would be approximately 450 m^3/h.

The overall yield features a fixed component (harvesting and emptying times) and a variable factor (journey times depending on the distance between harvesting and emptying points).

- Collection time recorded for 220 m^3: 33 min, or approx. 450 m^3/h.
- Emptying time: Not recorded - the seaweed was directly discharged into the sea after collection.

For the trials, the navigation time for a round trip between the harvesting and emptying points was 9 hours for a collection time of 30 min, resulting in an overall yield for the trial of 25 m3/h. This yield must be set against the short collection period (demonstration only with no continuous collection) and no data on hopper emptying times.

Assuming the hopper takes 7 hours to fill (i.e. 400 m^3/h) and 9 hours of navigation (i.e. 16 hours in total), the yield when emptying would be about 175 m^3/h. **This figure appears very optimistic given that continuous pumping of 40% *Sargassum* at 1,000 m^3/h for 7 hours is highly unlikely.**

The overall yield for this system depends on:

- Density: A dense mat of seaweed significantly reduces harvesting time and increases the proportion of *Sargassum* pumped up.
- Available seaweed storage to fill the hopper;
- Travel distance between the harvesting and emptying points.

4.2.2.3.5 Costs

The cost of operating the TSHD is €1,000/h.

4.2.2.3.6 Strengths and weaknesses

Type of impact	Comments	
Yield	At this time, evaluating the yield is complex because a limited number of tests have been conducted. The maximum yield for a 9 hour round trip would be 175m^3/h. This figure may be an under-estimate given operational constraints.	
Suction width	The 4 m suction range is not wide enough to collect a seaweed mat without several sweeps	
Collection area	Inshore and offshore: A flawless system to pinpoint the locations and directions of seaweed mats is essential. It should be noted that part of the mats harvested offshore cannot beach on the shoreline.	
Fresh seaweed clean-up capacity (<48h)	The vessel's bow and stern waves were seen to disturb the mat of seaweed.	
Old seaweed clean-up capacity (>48h)	n/a	
Effect on beach erosion	Offshore harvesting methods help protect against erosion processes	
Impacts on marine wildlife	Out at sea, *Sargassum* mats provide shelter and a source of food for a wide range of species. Collecting them at this stage would therefore be harmful to the environment.	
Mobility	The TSHD is relatively static once it reaches the *Sargassum* stranding, making it quite unlikely to harvest the whole mat of seaweed.	
Workers' health and safety	Fresh seaweed is harvested at sea.	

4.2.2.3.7 Areas for improvement

Key areas for improvement can be identified for the current set-up:

- The location and estimated surface area of the *Sargassum* mat must be identified beforehand to ensure that the TSHD is the right tool for the job.
- Widening the harvesting area using booms to channel the mat towards the trailing drag head. The trial was inconclusive due to the sea conditions. Nevertheless, this kind of system would help increase the harvest area and cut the number of passes needed, thereby reducing the likelihood of the mat spreading out.
- Placing the trailing drag head at the front of the vessel.

4.2.2.3.8 Conclusions

Key points to note

The trailing suction hopper dredger is a mechanised offshore harvesting tool that pumps the seaweed.

The system can achieve high collection yields when used in optimal conditions on a large, dense mat of seaweed located offshore.

However, this method is relatively immobile and its rather narrow collection mouth means the vessel must make several passes to clear a mat of seaweed. Each pass scatters the seaweed, reduces mat density and, as such, affects its collection yield. This system also has high hourly operation costs of approx. €1,000/h. The size of the vessel means it cannot berth at any location, so the time taken to reach the sargassum mats at sea can be long. Furthermore, pinpointing the location of the sargassum mats is still a problem and requires suitable reconnaissance capabilities.

The seaweed can be disposed of at sea in areas where the currents do not flow towards the coast, or it can be discharged on land. In the latter case, the TSHD is likely to discharge a very large quantity of sargassum seaweed compared to the options currently available and can therefore result in the vessel being out of action while it is emptied.

Currently, harvesting sargassum strandings offshore using this type of method appears ineffective in terms of its high hourly cost, major limitations to use (seaweed mats must be accurately identified, in sufficient quantities) and the intricacy needed when approaching the mats of seaweed (bow and stern wave scatter, narrow suction mouth, limited manoeuvrability, etc.).

Consequently, offshore harvesting seems to make little sense due to the seaweed scattering, the complexities when approaching the seaweed, reconnaissance needs and the large amounts to be collected, part of which will not reach the coast.

4.2.2.4 Offshore pumping systems - Mobitrac amphibious vehicle

Mechanised offshore harvesting operations using a prototype pumping system mounted on an amphibious vehicle were conducted at Robert and François.

4.2.2.4.1 Labour requirements

During the inspections, staff present included:

- A pilot to operate the vehicle
- A support worker on land to manage the hopper and discharge hose.

4.2.2.4.2 Equipment requirements

The Mobitrac is a prototype amphibious vehicle fitted with a 50 m^3/h pumping system connected to a suction nozzle of approx. 0.5 m at the front of the vehicle. It also has a flexible discharge hose to empty the seaweed on land. This method is designed to access bays from the shore and pump the seaweed lying there.

Figure 52: Mobitrac prototype

4.2.2.4.3 Seaweed collection arrangements

The Mobitrac uses a suction and discharge system for seaweed pumped directly into a hopper on land. It harvests and empties simultaneously, without any transfer time.

4.2.2.4.4 Estimated yield

The yield has been estimated by comparing the Mobitrac's actual operating time (minus stoppages) to the rate the collection hopper is filled.

Points to note

During the test at Robert, there was virtually no sargassum in the sea. As a result, no yields could be recorded for this particular trial. Only the test run at François was sufficient to secure an initial estimate.

While on-site, it was observed that the amount harvested in one hour of pumping was about 10-20% of a 20 m^3 hopper, i.e. a yield of less than 5 m^3/h (2-3 m3/h recorded).

There are three main reasons for this low yield:

- The Mobitrac's inability to move forward and pump simultaneously as only one function is possible at the same time. As such, once the seaweed in front of the nozzle has been pumped up, only water is left.
- An intake cone with a narrow range due to the small size of the harvester and an undersized pumping system.
- One major difficulty is moving the Mobitrac once the discharge pipe is full. The weight of the pipe and resulting friction brought the Mobitrac to a standstill and the pipe had to be uncoupled for the vehicle to be repositioned.

It should be noted that the proportion of water pumped up was high, so an appropriate collection hopper should be used to evacuate the water at rate higher or equal to that of the pump.

4.2.2.4.5 Strengths and weaknesses

Type of impact	Comments	
Yield	The highest yield during the trials was less than 5 m^3/h	
Suction width	Suction width less than 1 m	-
Collection area	Bay ends	
Fresh seaweed clean-up capacity (<48h)	Complex harvesting arrangements despite no observed jams	
Old seaweed clean-up capacity (>48h)	Not observed	
Effect on beach erosion	Offshore harvesting helps protect against erosion processes	
Beach load bearing capacity (formation of ruts, bogging down)	Use of caterpillar tracks for the amphibious part	
Impacts on marine wildlife	n/a	
Mobility	When not pumping, the Mobitrac is mobile and can easily reach mats of seaweed from the shore. When pumping, the Mobitrac has great difficulties moving about. It cannot pump and manoeuvre at the same time and the discharge pipe resists strongly when full.	 
Workers' health and safety	The team works in the open air and, as such, can be directly faced with: o H22 risks; o Odour nuisances. o Weather conditions (sun, rain). However, as the seaweed is harvested offshore, the effects are less serious than on land due to wind direction and less seaweed rotting in the water.	 

4.2.2.4.6 Areas for improvement

The vehicle is a prototype and the main areas identified for improvements during trials concern:

- A more powerful pump.
- A harvesting area as wide as the vehicle itself.
- Use of the motor and the pump at the same time to harvest seaweed while moving.
- Additional motors to move about with a full discharge hose.
- A hopper designed to evacuate the pumped seawater but retain the seaweed. The seawater discharge flow must be higher or equal to the pumping flow rate.

4.2.2.4.7 Conclusions

Key points to note

The method tested involves the amphibious vehicle being coupled to a pumping system to operate on bay floors.

It delivered an overall yield of 2-3 m^3/h in its current state (approx. 5% of pump flow rate).

This yield could be improved but remains restricted by

- *Mobitrac's mobility when pumping.*
- *The size of its pump.*

In its current set-up, the system must be improved before it can be considered as a harvesting method. This particular technique (pumping in-situ using an amphibious vehicle) can pave the way to optimising the logistical chain. Seawater discharge volumes must be correctly managed to avoid disruptions, especially if pump flows are increased.

To work properly, this method must be connected to a device to concentrate the seaweed (a floating barrier) and retain it in an area with enough draft for the vehicle, thereby reducing the area to locate the seaweed at sea.

4.2.2.5 Crane operation

The SLTP company carried out mechanised onshore seaweed collection operations using a crane and mesh cage.

Two operations have been evaluated:

Date	Municipality	Site
14/08/2018	PETIT BOURG	Port de Plaisance
16/08/2018	PETIT BOURG	Port de Plaisance

4.2.2.5.1 Labour requirements

During the evaluations, the staff required to operate the system on-site comprised two machine operators and a worker to hook up the hopper to the mobile crane.

4.2.2.5.2 Equipment requirements

The mobile crane is a mechanical lifting unit with a telescopic arm to work from the shore to a distance of approximately 30 m. A mesh cage is lifted into the sea and rakes the seabed or the surface to harvest the seaweed.

Figure 53: The crane

4.2.2.5.3 Seaweed collection arrangements

During testing, only bay end trawling operations could be observed (recovering old submerged seaweed)**. As no *Sargassum* seaweed had washed up on the shore during operations, no seaweed harvested on the surface was observed.**

Seaweed is collected from the shore, with a mesh cage attached to the crane and submerged in the sea water. The crane moves around to rake the sea floor with the cage to collect a mix of sediment, rotting seaweed and water. This mix is then brought to the surface and emptied on land. A digger then gathers up the mix and loads it on to a tipper truck.

Figure 54: Harvesting stages - submerging and emptying the cage

Figure 55: The mix collected by trawling the bay floor

4.2.2.5.4 Estimated yield

Only bay floor raking operations could be observed during testing. The average weight of one raking sweep was approximately 1.5 tonnes.

The yield is estimated based on the number of raking sweeps made by the crane in 1 hour. On average, it made 13 raking sweeps per hour.

At this rate, some 20 t/h of a mix of rotting seaweed, sediment and water could be harvested.

With no surface seaweed harvesting observed (no *Sargassum* strandings during the test, so the method was subsequently discontinued), the related yield could not be identified.

4.2.2.5.5 Strengths and weaknesses

Type of impact	Comments	
Yield	When testing, the yield from raking the bay floor was roughly 20 t/h	
Suction width	30 m operating range from the shore	-
Collection area	Bay ends	
Fresh seaweed clean-up capacity (<48h)	Not observed	
Old seaweed clean-up capacity (>48h)	Using a crane helps harvest a considerable mix of sediment, rotting seaweed and water from the bay floors. This mix cannot be directly loaded into a tipper truck, resulting in well-rotten seaweed being dropped on the ground which is not easily harvested other methods.	
Effect on beach erosion	Offshore harvesting helps protect against erosion processes	
Beach load bearing capacity (formation of ruts, bogging down)	The crane requires a solid, stable surface to manoeuvre	
Impacts on marine wildlife	When dredging, the removal of substrate and stirring up sediments can damage the bay floor. In these cases, it should be noted that this damage should be compared to the highly negative impact of seaweed being washed up on the shore (anoxia, etc.). The system is unlikely to have a significant impact when harvesting seaweed on the surface.	
Mobility	Using a truck crane means that the system can be employed throughout the area, as long as the site is accessible (load bearing capacity, access road, etc.).	
Workers' health and safety	While the cabins are air conditioned, the workers must wear suitable protective equipment (masks, etc.). Raking sea floors severely affected by *Sargassum* strandings can cause foul smells in the surrounding area after well-rotted seaweed has been moved.	

4.2.2.5.6 Conclusions

Key points to note

A crane can be used to collect submerged or floating seaweed close to the coast from the shoreline by raking the surface with a small mesh cage.

On average, 13 raking cycles can be carried out in 1 hour. At the present time, only collections of rotten seaweed from the bay floor could be observed, with an average weight of 1.5 t per raking sweep (mix of seaweed, sediment and water).

4.2.2.6 Offshore harvester – SOTRADOM

The SOTRADOM company in was going to test an offshore harvesting barge in Guadeloupe. However, due to structural and stability problems, the method could not be tested and was subsequently abandoned.

4.2.2.7 Offshore collection treadmill

A seaweed collection treadmill was to have been tested in Guadeloupe. However, due to problems with equipment (malfunctions) and organisational arrangements (lack of sargassum) the method could not be evaluated.

4.2.3 Manual onshore collection

Manual clean-ups gather *Sargassum* seaweed using hand tools.

Two companies have used this method and have been evaluated:

- The CAID Patrimoine Association that runs employability work camps.
- The Martinique RSMA (Adapted Military Service Regiment), which was called in by the Prefecture in 2018 to assist beach cleaning efforts.

The principle for clearing seaweed was the same for both organisations and the evaluation findings are jointly presented.

Table 3: Supervised beach cleaning operations

Date	Municipality	Site	Organisations
03/12/2015	VAUCLIN	Pointe Faula	CAID Patrimoine
07/06/2016	ROBERT	Pontaléry Nord	CAID Patrimoine
23/08/2016	SAINTE ANNE	Anse aux bois	CAID Patrimoine
18/05/2018	SAINTE ANNE	Anse Michel	RSMA

4.2.3.1 Labour requirements

The beach cleaning teams numbered 6 to 20 people. Each team had:

- A supervisor
- Workers

The RSMA also had a medical team consisting of:

- Two firefighters
- A doctor
- A nurse
- A medical assistant

4.2.3.2 Equipment requirements

The teams must be supplied with proper **protective equipment** (see section 4.2.1.2, p51)

The collection tools observed for beach cleanings were:

- For gathering seaweed:
  - Rakes, forks and shovels
  - Wheelbarrows (100 L and 150 L)

Figure 56: Manual beach cleaning tools – Green Brigades – Pointe Faula

- For disposal: Unrinsed seaweed, the *Sargassum* is piled on the top of the beach for removal later by mechanical diggers or in open skips provided by the municipalities.

Figure 57: Storage area at the top of the beach – Green Brigades – Anse Aux Bois

Figure 58: Storage in open skips – Pointe Faula

The RSMA clean-ups also used excavators, while an intensive care ambulance was also present on site.

4.2.3.3 Seaweed collection arrangements

The team members split into two roles:

- Gathering seaweed and filling wheelbarrows and;
- taking wheelbarrows to the disposal point and emptying them.

Splitting the workers into different roles largely depends on the number of clean-up tools available and the layout of the beach. Working in pairs (one gathering, one wheelbarrowing) seems to be a natural way to organise the workers.

The seaweed is collected on the sand and taken to the top of the beach, to a centralised disposal area to then be collected by an external contractor using a mechanised collection method. This helps to:

- Avoid moving heavy machinery about on the beach.
    - Reduce the impact on the beach (erosion, creating ruts, etc.).
    - Cut the effects on the environment (limiting journeys over the vegetation, no risk of trampling sea turtle nests, etc.).
- Centralise seaweed dumping.
    - Free up space on the beach for other users and for future *Sargassum* strandings (reducing the detrimental effects on the marine environment).
    - Simplify clearing operations for motorised machinery.

4.2.3.4 Estimated yield

The overall yield was determined by counting the number wheelbarrows taken away to the disposal area in a given time and for a set number of workers. The level to which the wheelbarrows were filled was also systematically checked by eye.

These yields were converted to m^3/h/person to compare them with other evaluations (the number of workers and team organisation arrangements could vary).

The findings are summarised in the table below:

Table 4: Data summary – Manual beach clean-up

Site	Vauclin (Pointe Faula)	Le Robert (Pontaléry)	Sainte Anne (Anse aux Bois – test 1)	Sainte Anne (Anse aux Bois – test 2)	Sainte Anne (Anse Michel)
Organisation	CAID	CAID	CAID	CAID	RSMA
Team organisation arrangements	Pairs	Pairs	Pairs	66 % cleaning up – 33 % transporting	Pairs
Number of workers	6	11	10	6	8
Weather conditions	Good	Good	Good	Good	Good
Average thickness (m)	0.01	(Shoreline harvesting)	0.4	0.4	0.01
Seaweed stranding date	<48h	<24h + >48h	<48h	<48h	<24h
Average wheelbarrow filling level (%)	150	80	140	135	115
Average distance round-trip collection to disposal point (m)	40	20	30	30	80
Average amount gathered in en 1h (m^3)	17.5	6.2	25.8	21	4.4
Yield in m^3/h/person	2.9	0.56	2.6	3.5	0.55
Easy to gather?	Yes	No	Yes	Yes	Yes

In terms of team arrangements (pairs), there does not seem to be a strong relationship between the overall yield and the type of seaweed stranding (fresh or old).

Yields do however appear strongly dependent on:

- The distance between the collection and emptying points. Yields are low when distances are long (e.g. Anse Michel).
- Average wheelbarrow filling levels.
- Team organisation. It should be noted that for the same site, altering team organisation arrangements resulted in significant changes to yields (25% increase at Anse aux Bois). This

is due to the fact that seaweed collection and wheelbarrow transfer times were not synchronised. Yield rates depend on:

- The nature of strandings, which impacts on collection. The denser the stranding onshore, the easier it is to gather. It should be noted that when the stranded seaweed is too dense, there is an adverse effect due to it rotting and producing H_2S that puts the clean-up teams' health at risk.
- The distance between collection and emptying points. The shorter this is, the quicker the wheelbarrow transfers.

The evaluation at Pontaléry found that the site was not suited to a manual clean-up as the teams had to walk into the sea to gather part of the *Sargassum*.

The overall yield appears to be 2.5 to 3.5 m^3/h/person, with optimum performance being roughly 3.5 m^3/h/person.

Figure 59: Beach clean-up before and after 2 hours work – Green Brigades – Pointe Faula

4.2.3.5 Staff and equipment costs

The costs are generated from data provided by CAID Patrimoine and costs displayed in supermarkets and specialist shops.

- Cost of equipment:
  - PPE: €100/person
  - wheelbarrows: €55 each
  - forks, shovels: €15-20 per tool

  - H_2S gas detector: €100-€400 according to model, i.e. an average cost of €250 per person;
- Staff costs: The cost of an employability scheme worker (ACI) is approximately €35 per hour.

The average daily cost over one year can be estimated based on:
- One team of 10 people.
- Equipment: 3 wheelbarrows, 7 forks/shovels and 2 H_2S detectors.
- The renewal of worn or damaged wheelbarrows, forks and shovels.
- PPE and H_2S gas detectors renewed annually.
- Legal maximum of 1,602 working hours per year and 46 working weeks (35 hours per week, 5 day a week).

The annual cost of equipment for one team of 10 people on an employability scheme is €2,415 (or €240 per person per year) and €560,700 for staff costs.
This results in an average daily cost (based on a 5-day week) of €250 per person.

4.2.3.6 Value for money

In optimum circumstances, the average yield is 3.5 m^3 per hour per person.

Excluding the cost of equipment, this equates to a cost price for one employee of €10 per m^3. Given that 1 m^3 of fresh, wet seaweed weighs an average of 300 kg, the average cost is €30 per tonne.

In sub-optimal conditions (60% of the optimum yield), the average yield is about 2.1 m^3 per hour per person.

Excluding equipment costs, this corresponds to a cost price for one employee of €17 per m^3. Given that 1 m^3 of fresh, wet seaweed weighs an average of 300 kg, the average cost is €51 per tonne.

In non-optimal conditions (30% of the optimal yield), the average yield is about 1 m^3 per hour per person.

Excluding equipment costs, this corresponds to a cost price for one employee of €35 per m^3. Given that 1 m^3 of fresh, wet seaweed weighs an average of 300 kg, the average cost is €105 per tonne.

4.2.3.7 Strengths and weaknesses

Type of impact	Comments	
Yield	Theoretical yield of 2-3.5 m^3 per hour per person in optimal circumstances. The yield remains dependent on the distance between the stranding area and the disposal point in terms of the reduced amount wheelbarrowed (many return journeys)	
Optimal thickness (m)	> 0.1 m	-
Fresh seaweed clean-up capacity (<48h)	Very good	
Old seaweed clean-up capacity (>48h)	Significant rise in H2S risk and weight of seaweed (compacting), complicating clean-up tasks.	 
Effect on beach erosion	The amount of sand collected is low, accounting for 1% of volume gathered, making this method ideal for regular clean-ups.	
Beach load bearing capacity (formation of ruts, bogging down)	Low due to the light weight of equipment and workers	
Risk of crushing sea turtle nests and vegetation	Low due to the light weight of equipment and workers. Potential risk for nests if seaweed is stored on the top of the beach.	 
Mobility (excl. load bearing capacity)	Movements on-site are on foot, mobility being reduced in the case of long straight lines	 
Workers' health and safety	Beach teams must deal directly with: - H_2S risks; - Odour nuisances. - Weather conditions (sun, rain). - Physical and mental fatigue.	

4.2.3.8 Areas for improvement

Areas for improvement could include:

- **Greater yields**:
  - Altering the distribution of tasks in teams according to the sites and spread of seaweed strandings. This means allocating as many workers as possible to time-consuming tasks to secure a balance between gathering and transferring. This will help avoid any dead time in the clean-ups.
  - Making wider use of small tools (seaweed rakes, compost forks, etc.) to tailor seaweed gathering methods to stranding patterns.

Points to note

The use of mechanised collectors has a high environmental impact when supporting manual beach clean-ups (diggers, etc.) and is discouraged as they also remove large quantities of sand (20 – 50 % of the amount observed in-situ) which detracts from the positive outcomes of manual beach clean-up methods.

- **Managing gathered seaweed**:
  - By providing low-lip skips that can be directly filled by the Green Brigades and emptied at the end of each day or beach clean-up.
  - Or by using the heaps of seaweed on-site:
    - Using it as undergrowth mulch.
    - Spreading it out to rot naturally without fermenting. The seaweed rots down naturally and doesn't produce H_2S in the case of anaerobic decomposition: Spreading it out to a maximum of 10cm in depth will ensure it rots naturally in the right conditions.

4.2.3.9 Conclusions

Key points to note

Manual clean-ups have many advantages such as:

- **Yield**: A team of 10 people can gather 25-35 m^3 per hour in good conditions.
- **An environmentally-friendly method**: Areas to be clean can be targeted. No risk of compaction and the tools used will not harm the beach.
- **Low amount of sand collected**: Around 1% of the total amount and less than 5% of weight for $1m^3$ of fresh seaweed. This helps significantly limit beach erosion with regular clean-ups.
- **Ease of access**: Green Brigades can access beaches off limits to vehicles.
- **Smart gathering**: manual clean-ups can sort and separate seaweed and large items of waste (plastic bottles, etc.) on the beach.
- **Versatility for different types of seaweed strandings, with the potential of non-beach applications** (cleaning up green spaces)**.**
- Low-cost equipment (approx. €240 per person per year).
- **Neat and tidy outcome**.
- **Social inclusion role** to partly address employment issues in the case of the employability beach clean initiatives.

... And a few disadvantages:

- **Needs large numbers of people**: The yield is directly related to the number of people on-site.
- **Significant health risks**: Green Brigades are exposed to heat and H_2S, which limits their performance in the event of large quantities of rotting seaweed and more arduous working conditions. For the most extreme cases, only specialist staff trained in high-risk tasks can wear self-contained compressed air breathing apparatus for manual beach cleans. Proper PPE checks are vital.
- **No direct disposal**: Green Brigades have no tools to directly fill skip trucks. They must pile the seaweed up first to then be gathered by a mechanised assistance to completely rid the site of seaweed. Placing the skip on the ground can overcome this part of the issue.

Teams on-site must be well managed and sufficient thought should be given to what happens to the seaweed gathered if manual beach clean-ups are to be successful. The use of manual beach clean-ups must mainly focus on low H_2S-risk sites.
The cost of employing this method depends on the number of people requested, the cost being €250 per person per working day for those on employability schemes.

4.2.4 Mechanised onshore clean-up

4.2.4.1 Cane loader

The PROGRES Cuma Company carried out mechanised onshore seaweed collection operations using a cane loader.

The operation was evaluated over two days:

Date	Municipality	Site
07/09/2018	Marie Galante	Boulevard maritime
18/09/2019	Marie Galante	Petite Anse

4.2.4.1.1 Labour requirements

During the evaluation, the staff needed to operate the cane loader on-site was limited to 1 driver. It should be noted that a digger was also used during the trials to pile the beached *Sargassum* into thicker heaps.

4.2.4.1.2 Equipment requirements

The cane loader (a BELL 125, in this case) is a piece of farm machinery fitted with a front-facing grapple-grabber to load sugar cane. The cane loader chassis has three wheels, one at the rear to steer it. Its short-reach hydraulic arm can be used to gather seaweed from the ground. This machine has a motor, hydraulic parts (pump, motor, cylinders), a driver's cabin and collection attachments (arm, boom, swinging arm and grapple).

Figure 60: A cane loader

The main features are shown below (source: manufacturer's data for the 125F model):

- **Length**: 5.72 m
- **Width**: 2.75 m
- **Grapple volume**: 0.36 m^3
- **Grapple max. load**: 1,100 kg
- **Grapple lifting height:** 5.6 m

The driver's cabin is unglazed and therefore not air-conditioned. The cane loader requires just one driver.

4.2.4.1.3 Seaweed collection arrangements

Collection arrangements are described in section 4.2.1.1, p50.

4.2.4.1.4 Estimated yield

The yield is calculated by measuring the time taken to fill one 14 m^3 skip. Two set-ups were evaluated:

- One set-up with piles of seaweed prepared by a digger on-site (thick heaps).
- One set-up to collect scattered, thinly matted seaweed.

It should be noted that in the first case, the distance between the seaweed stranding area and the skip was very short, limiting time lost on moving between collection and emptying points.

Table5: Data summary – Cane loader

Site	Boulevard maritime	Petite Anse
Organisation	LE PROGRES Cuma	LE PROGRES Cuma
Weather conditions	Good	Good
Average thickness (m)	> 0.5	0.1
Extent of coverage	100 %	30/40 %
Seaweed stranding date	< 48h	< 48h
Average time to fill one 14 m3 skip (min)	4 / 5	20 / 25
Overall yield in m^3 per hour	170 - 210	30 - 40
Easy to gather?	Yes, emptying skip right next to the collection point	Yes

The collection yield depends on the following aspects:

- The type of stranding: A large, thick seaweed stranding (> 50 cm) results in a significant rise in yield. It **should be noted that the observed yield was optimistic as the loader did not have to manoeuvre to gather while a second digger supplied it with seaweed.** A maximum potential yield of 100 to 150 m^3 per hour would be more realistic.
- The distance of travel between the seaweed collection point and the drop-off area in tipper trucks. As the cane loader's grapple capacity is relatively small (0.37 m^3), it had to make numerous round trips to clear the scattered seaweed. It should be noted that when disposing of the seaweed in tipper trucks, having a truck always on-site cannot be guaranteed due to the travel time to empty the skip.

4.2.4.1.5 Costs

The costs are taken from data supplied by the operator: daily hire fee (€750, including maintenance).

A cane loader can directly fill a skip without needing an intermediary step in the clean-up.

4.2.4.1.6 Strengths and weaknesses

Type of impact	Comments	
Yield	The cane loader yield depends heavily on stranding density and distance between the collection and emptying points due to its limited grapple capacity. ○ The type, thickness and extent of coverage of the stranding ○ The distance between the stranding area and disposal point given the reduced size of the tipper truck (numerous round trips required)	
Optimal thickness (m)	> 0.5 m. Can use loader for thinner mats	-
Fresh seaweed clean-up capacity (<48h)	Very good	
Old seaweed clean-up capacity (>48h)	Not observed	
Effect on beach erosion	At the time of the evaluation, the seaweed was mostly mixed with sand due to the use of the additional digger	
Beach load bearing capacity (formation of ruts, bogging down)	The cane loader is highly sensitive despite use of low-pressure high-load-bearing tyres	
Risk of crushing sea turtle nests and vegetation	Yes, in the case of movements on the upper part of the beach. Care must nevertheless be taken when manoeuvring.	
Mobility (excl. load bearing capacity)	Excellent mobility. Collection does not depend on where the tipper truck is positioned.	
Workers' health and safety	As the driver's cabin is open, they must have an H_2S gas detector and mask.	

4.2.4.1.7 Conclusions

Key points to note

The cane loader is a mechanised method for onshore clean-ups.
During the trials, the collection yield was highly dependent on stranding thickness: from 30-40 m^3/h for thin mats of seaweed (0.1 - 0.2 m) to 170 - 210 m^3/h for already formed heaps of seaweed (corresponding to thick sargassum strandings).

As a result, this type of equipment is best used to either supplement another heavy-duty collection method, such as a mechanical digger (not recommended due to beach erosion) or for mass strandings more than 0.5 m thick.

In terms of the latter, as the driver's cabin is open to the elements, the driver must have an H_2S gas detector and mask with them.

Care must be taken to avoid the risk of beach erosion. Using a grapple to clear dense strandings limits the risk as it removes little sand, although it does mix sand with seaweed when lifting thin mats of seaweed.

4.2.4.2 Surf rake

The SEEN Company carried out mechanised onshore seaweed collection operations using a surf rake.

Five operations were evaluated:

Date	Municipality	Site
10/09/2015	DIAMANT	Anse cafard
06/10/2015	SAINTE ANNE	Anse aux bois
18/09/2015	SAINTE MARIE	La Richer
23/10/2015	SAINTE MARIE	Plage du Bourg
30/10/2015	VAUCLIN	Plage du Bourg

4.2.4.2.1 Labour requirements

During the evaluations, only one driver was required to operate the surf rake.

4.2.4.2.2 Equipment requirements

The surf rake (BARBER 600HD used here) is a tractor-towed machine with tines fitted to a conveyor belt that rakes up seaweed and rubbish from the beach surface. It is fitted with a 2.3 m^3 storage hopper.

Figure 61: The surf rake

The main features are shown below (source: Manufacturer's data):

- **Pulling power**: 4x4 agricultural tractor (60 cv minimum);
- **Tyres**: 36 x 13,5 x 15 low-pressure high load-bearing tyres;

- **Operating width**: 2.13 m with a 1.83 m conveyor width
- **Operating depth**: 0 to 15.24 cm
- **Hopper capacity**: 2.3 m^3 (2 t)
- **Hopper lifting height**: 2.74 m
- **Operating speed**: up to 24 km/h
- **Weight** approx. 1.7 t

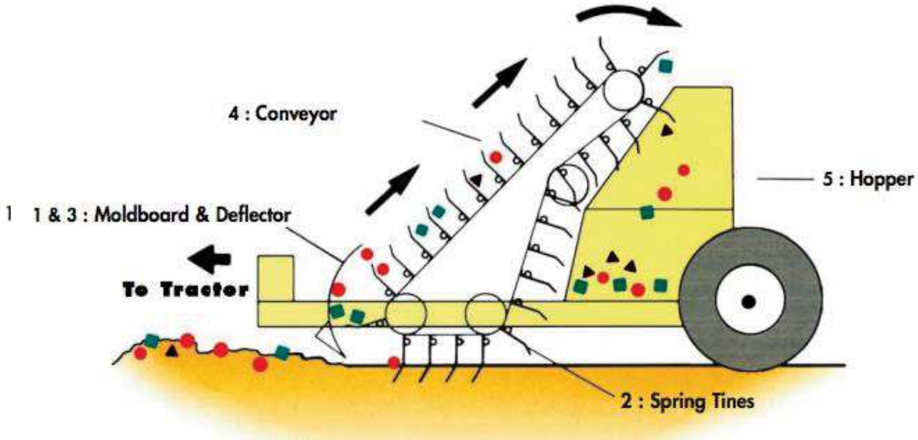


Figure 62: Surf rake operating diagram (source: http://www.hbarber.com)

The tractor can also be fitted with a frontal claw bucket to lift any obstacles or large or compact items of rubbish, or to gather very thick mats of *Sargassum*.

Figure63: Claw bucket

The driver's cabin is air-conditioned and fitted with an H_2S gas detector. The surf rake requires just one driver.
In addition to the surf rake, 8 and 11 m^3 tipper trucks were provided to take away the seaweed.

4.2.4.2.3 Seaweed collection arrangements

Collection arrangements are described in section 4.2.1.1, p50.

4.2.4.2.4 Estimated yield

The yield is calculated by timing all the stages in the clean-up cycle and over several cycles.

Table 6: Data summary – Surf rake

Site	Diamant (Anse Cafard)	Sainte-Marie (Azérot)	Sainte-Marie (Plage du bourg)	Vauclin (Plage du bourg)
Organisation	SEEN	SEEN	SEEN	SEEN
Weather conditions	Good	Good	Good	Good
Average thickness (m)	0.2	0.2	0.04	0.12
Extent of coverage	100 %	40 %	5 %	90 %
Seaweed stranding date	< 48h	> 72h	> 72h	< 24h + > 48h
Average collection time (s)	60	-	446	150
Average round trip transfer time: collection area to tipper truck(s)	180	-	380	60
Average emptying time (s)	30	-	40	42
Overall yield in m^3 per hour	35	-	8.7	31
Easy to gather?	Yes	No - load bearing problems leading to tractor getting stuck in the sand	Moderate - scattered stranding, partially buried	Yes

Given these figures, we can say that:

- Skip emptying time varies little and is very quick (approx. 30-40s);
- The collection time varies considerably based on stranding thickness and extent of coverage. The greater they are the quicker the clean-up. If, however, the *Sargassum* mat is too thick (> 0.3/0.4 m according to reports from the technical service teams at Diamant), using the surf rake becomes more complicated (difficulty to move around on the stranding and numerous passes needed).
- Transfer time also varies from site to site.

The overall collection yield using the surf rake is roughly 30-35 m^3 per hour but can be improved as the driver was new to this system during the trials. A yield of 30 to 50 m^3 per hour appears achievable in optimal conditions, including:

- Fresh strandings (< 48h) and less than 0.3 m.
- Large stranding area.
- Good load bearing on beach.
- Experienced driver.

Figure 64: Before and after (Anse Cafard – Le Diamant)

Figure 65: Before and after (Plage du Bourg – Le Vauclin)

4.2.4.2.5 Costs

The costs are provided by SEEN and ADEME (prices as of March 2015 and subject to change).

- **Cost of investment in equipment** (excl. tax and transport):
  - Surf Rake 600 HD: €53,480 (excl. tax).
  - Standard surf rake attachment €8,960 (excl. tax).
  - Tractor 100 cv 4x4 with frontal loader: €50,000 (excl. tax).

- **Daily hire fee (including maintenance)**:
  - Tractor + 600 HD Surf Rake + driver + maintenance: €1,175 per day.
  - Transport round-trip: €450.

In optimal circumstances for the set-ups tested, the peak yield is approx. 40 m^3 per hour.

On a day-hire basis (assuming 5 hours on-site), this corresponds to a cost price of approximately €8 per m^3 collected. If 1 m^3 of seaweed weighs on average, 300 kg, the average cost is roughly €24 per tonne.

In sub-optimal circumstances (60 % of the optimal yield), the average yield is approx. 24 m^3 per hour.

On a day-hire basis (assuming 5 hours on-site), this corresponds to a cost price of approximately €14 per m^3 collected. If 1 m^3 of seaweed weighs on average, 300 kg, the average cost is roughly €42 per tonne.

In non-optimal conditions (30 % of the optimal yield), the average yield is approx. 12 m^3 per hour.

On a day-hire basis (assuming 5 hours on-site), this corresponds to a cost price of approximately €27 per m^3 collected. If 1 m^3 of seaweed weighs on average, 300 kg, the average cost is roughly €80 per tonne.

It should be noted that having the surf rake and claw bucket together means the tipper truck can be loaded directly without the need for an intermediate stage.

Figure 66: Directly loading a tipper truck

4.2.4.2.6 Strengths and weaknesses

Type of impact	Comments	
Yield	Overall yield of 30-50 m^3 per hour in optimal conditions (moderate stranding thickness over large areas). Yield is highly dependent on: - The type, thickness and extent of coverage of the stranding - The distance between the stranding area and disposal point given the reduced size of the tipper truck (numerous round trips required)	
Optimal thickness (m)	0 - 0.2 m. Option of using system up to 0.3 - 0.4 m - Operating difficulties reported above this thickness.	-
Fresh seaweed clean-up capacity (<48h)	Very good	
Old seaweed clean-up capacity (>48h)	It may be necessary to make more sweeps and difficulties may be experienced when clearing thick swathes of compacted seaweed in huge heaps	
Effect on beach erosion	The observed amount of sand collected is relatively low (1-2% of harvested amounts), except for specific cases such as seaweed buried in the sand, which makes the system ideal for regular clean-ups.	
Beach load bearing capacity (formation of ruts, bogging down)	High sensitivity for the tractor despite the use of low-pressure, high load-bearing tyres.	 
Risk of crushing sea turtle nests and vegetation	Yes, in the case of movements on the upper part of the beach. Care must be taken when manoeuvring the surf rake.	 
Mobility (excl. load bearing capacity)	Excellent mobility. Collection does not depend on where the tipper truck is positioned.	
Workers' health and safety	Equipment for driver safety and good working conditions (elevated cabin, H_2S gas detector, air-conditioning)	

4.2.4.2.7 Areas for improvement

The main areas to seek improvements are:

- **Load-bearing capacity**: The system can get bogged down and create ruts on some beaches, leading to the surf rake getting stuck, or partial and localised damage to the beach (wheel marks, damage to mounds between the beach and land, etc.).
- **Improved transfer times**, once the surf rake hopper is full, from the clean-up site to the tipper truck. These trips account for almost 2/3 of the time to complete one full collection cycle. It is vital that tipper trucks are properly positioned.
- **Maintaining a thin coat of seaweed on the surface (debris line)** to help physically protect against beach and environmental erosion (source of food and shelter)

Points to note

As with all collection methods, the removal of seaweed to another site must be properly managed to not bring the surf rake to a standstill when tipper trucks are unavailable to fill.
Using a claw bucket on the front of the tractor can partially overcome this problem as the seaweed can be directly heaped on the ground while waiting for the tipper truck and quickly loaded when it arrives.

4.2.4.2.8 Conclusions

Key points to note

The surf rake is a mechanised method for onshore clean-ups.

It delivers collection yields of 28 - 35 m^3 per hour in good operating conditions:

- Beach accessible to heavy machinery with enough load-bearing capacity.
- Fresh dense or scattered strandings (less than 48 hours) less than 30 cm thick.

This system also offers good mobility on roads and beaches and causes little physical damage to beaches (small proportion of sand collected with the seaweed). It leaves the beach visibly clean by efficiently cleaning up thin layers of seaweed.

Specific attention should be given to:

- The risk of getting bogged down in low load-bearing capacity beaches.
- The distance between the stranding and tipper truck as numerous round trips hugely impact operational yields.

The surf rake is mainly used to maintain beaches and must be used regularly in the event of strandings to avoid too much seaweed building up on the beach. It provides a visually 'clean' result by efficiently cleaning up thin layers of seaweed

4.2.4.3 Mechanised onshore seaweed collection: Self-propelled collection vehicle

The AXINOR Company was tasked with carrying out mechanised onshore seaweed collection operations using a self-propelled harvester (a modified agricultural vehicle).
Four operations were evaluated:

Date	Municipality	Site
27/06/2017	VAUCLIN	Pointe Faula
30/06/2017	VAUCLIN	Plage du Bourg + Pointe Faula
03/07/2018	LE DIAMANT	Anse Cafard
05/07/2018	LE DIAMANT	Beach No.8

4.2.4.3.1 Labour requirements

During the evaluation exercises, on-site staff present included:

- 1 driver
- 1 companion

Ultimately, **only one person** would be required.

4.2.4.3.2 Equipment requirements

The AXINOR self-propelled harvesting vehicle is a mechanised seaweed prototype (a modified farm vehicle) that combs the beach surface with tines attached to a treadmill to pick up seaweed and rubbish. The waste gathered is then transferred to the vehicle's 20 m^3 hopper via a series of conveyors: a horizontal belt that takes the seaweed under the hopper and a lateral belt to fill it.

Figure 67: The self-propelling vehicle

The main features are shown below (manufacturer's data):

- **Dimensions** length 10 m, width 2.5 m, height 3.5 m;
- **Tyres**: Low-pressure, high load-bearing tyres;
- **Operating depth**: Adaptable from 0 to 15 cm;
- **Hopper capacity**: 20 m^3;
- **Speed** : 40 km/h;
- **Tare weight**: 15 t ;
- **Payload**: 15 t.

The driver's cabin is air-conditioned and fitted with an H_2S gas detector and activated carbon filters. The vehicle requires just one driver.

4.2.4.3.3 Seaweed collection arrangements

Collection arrangements are described in section 4.2.1.1, p50.

4.2.4.3.4 Estimated yield

As trials were conducted in areas where the hopper could not be systematically filled to the brim, the vehicle's overall yield was estimated based on the time taken to fill a tipper truck on the beach.

Table 7: Data summary – Self-propelled vehicle

Site	Vauclin (Pointe Faula)	Vauclin (Plage du bourg)	Diamant (Anse Cafard)	Diamant (Beach no.6)
Organisation	AXINOR	AXINOR	AXINOR	AXINOR
Weather conditions	Good	Good	Good	Good
Average thickness (m)	0.2 / 0.3	0.2	0.6 / 1	0.5 / 0.8
Extent of coverage	100 %	80 %	100 %	100 %
Seaweed stranding date	< 48h + > 48h	< 48h	> 72h	<24h
Average collection time (s) / Average round trip transfer time: collection area to tipper truck(s)	660	840	-	1200
Average emptying time (s)	45	75	-	260
Overall collection yield in m per hour (for continuous harvesting)	100	80	-	45
Easy to gather?	Yes	Yes, beach narrow and tipper truck poorly positioned for loading.	Conveyor jam: seaweed too heavy (compacted + water)	No space for U-turn = yield halved (one-way collection only)

Given these figures, we can say that:

- Hopper emptying times vary little and are very quick (approx. 1 min). The trials at Le Diamant took longer but this was due to the skip always being on the tipper truck and not placed on the beach, making approach manoeuvres more difficult.
- The yield is high in good stranding conditions and on beaches able to bear heavy loads (approx. 100 m^3/h). This yield is due to the wide harvesting treadmill which can clear larger areas. Also, the vehicle's large hopper means it can stay longer operating in the stranding area and keep tipper truck transit times to a minimum.

  It should be noted that the vehicle is not hampered by very thick mats of seaweed (> 0.5 m). It continues to harvest by altering its speed to leave more time to gather the seaweed.
- Lateral conveyor jams were observed periodically that could halt harvesting and cause a net loss in collection yields. These jams were recorded when harvesting old, well-rotted seaweed, which are heavier than fresh strandings and tend to form clumps that can block the lateral conveyors. As this is a prototype harvesting vehicle, changes will be made to the existing model and future vehicles to eliminate this problem.

The overall collection yield from this method is 80 - 100 m^3/h in good conditions.

- Fresh stranding (< 48h) less than 0.2 m thick
- Large stranding area.
- Good load bearing on beach.
- Experienced driver.

Figure 68: Before and after (Pointe Faula – Le Vauclin)

Figure 69: Before and after (Beach no.8 – Le Diamant)

4.2.4.3.5 Costs

The costs have been taken from data provided by AXINOR and ADEME (prices as of March 2015 and subject to change)

- **Material investment cost** (excl. tax): €341,000

- **Daily hire fee (including maintenance)**: Hire not available. **We have assumed a day hire fee of €1,500** (observed cost for long-reach excavators)

In optimal circumstances, the best possible yield for the set-ups tested is roughly 90 m^3/h.

This would correspond to a cost price of around €3 per m^3 harvested, based on the assumption of 5 hours working on-site. Given that 1 m^3 of fresh, wet *Sargassum* seaweed weighs an average of 300 kg, the average cost is €9 per tonne.

In sub-optimal conditions (60% of the optimum yield), the average yield is about 54 m^3 per hour.

This would correspond to a cost price of around €6 per m^3 harvested, based on the assumption of 5 hours working on-site. Given that 1 m^3 of fresh, wet *Sargassum* seaweed weighs an average of 300 kg, the average cost is €18 per tonne.

In non-optimal conditions (30% of the optimum yield), the average yield is about 27 m^3 per hour.

This would correspond to a cost price of around €11 per m^3 harvested, based on the assumption of 5 hours working on-site. Given that 1 m^3 of fresh, wet *Sargassum* seaweed weighs an average of 300 kg, the average cost is €33 per tonne.

It should be noted that the self-propelling harvester vehicle can directly load a tipper truck without the need of an intermediary stage.

Figure 70: Directly loading a tipper truck

4.2.4.3.6 Strengths and weaknesses

Type of impact	Comments	
Yield	Theoretical yield of 80 - 100 m^3/h in optimal conditions. The yield is highly dependent on the type, thickness and extent of the seaweed stranding on the beach.	
Optimal thickness (m)	0.2 - 0.8 m. Below 0.1 m, the proportion of sand gathered rises steeply	-
Fresh seaweed clean-up capacity (<48h)	Very good	
Old seaweed clean-up capacity (>48h)	The weight of well rotting seaweed, as well as its texture (forms clumps) can cause the lateral conveyors to jam and halt harvesting operations.	 
Effect on beach erosion	The recorded amount of sand gathered is relatively low (about 1% of the quantity harvested) except when the vehicle harvests the 0 to 0.05 m layer, when the proportion of sand collected can rise to 5 - 10%. The self-propelling vehicle leaves a 0.05 - 0.1 m layer of seaweed after harvesting, which helps sustain the physical and ecological functions of beach debris lines.	
Beach load bearing capacity (formation of ruts, bogging down)	The vehicle is highly prone to this despite using low-pressure, high load-bearing tyres.	 
Risk of crushing sea turtle nests and vegetation	Yes, in the case of movements on the upper part of the beach. Care must be taken when manoeuvring the vehicle.	 
Mobility (excl. load bearing capacity)	Excellent mobility. Collection does not depend on where the tipper truck is positioned.	
Workers' health and safety	Driver safety equipment and good working conditions (elevated cabin, H_2S detector, air-conditioning)	

4.2.4.3.8 Areas for improvement

The main areas for improving the prototype are:

- **Load bearing capacity**: The vehicle got bogged down or created ruts on some beaches, which resulted in it getting stuck. This caused partial, localised damage to the beach (wheel marks, damage to mounds between the beach and land, etc.). This problem could be limited by:
  - Reducing the vehicle's size and weight;
  - Adding more wheels to better spread the load, or fit caterpillar tracks;
- **Vehicle size**: Given its large size, the entire length of the frontal treadmill is rarely used given how narrow the beaches are in Martinique. Also, its size means it can only be used on beaches with sufficiently wide and passable access roads. Reducing the size of the vehicle by 30 to 50% would make it more versatile.
- **Tackling conveyor jams**:
  - On the existing vehicle:
    - Strengthen the conveyor fins to stop them deforming when they encounter a heavier patch of seaweed;
    - Central and lateral conveyor speed regulator: If the lateral conveyor was faster than the central treadmill, the seaweed would be more evenly distributed and larger clumps of seaweed would not form;
    - Reduce the speed when harvesting old, rotting seaweed strandings (>48h) to prevent a sudden, large intake of seaweed.
  - On future vehicles: Remove the lateral conveyors and replace them with a sloping central belt.

4.2.4.3.9 Conclusions

Key points to note

The self-propelled harvesting vehicle is a mechanised onshore seaweed collection prototype.

It delivers collection yields of around 100 m^3/h in good operating conditions:

- Beach accessible to heavy machinery with enough load-bearing capacity.
- Fresh, dense strandings (less than 48 h old) 10 to 80 cm thick.

This system also offers good mobility on roads and beaches and causes little physical damage to beaches (small proportion of sand collected with the seaweed). The system can be used to harvest large, fresh seaweed strandings if its speed is altered.

Specific attention must be given to risks of:

- Lateral conveyor jams when harvesting compacted or soaking seaweed (heavy weight);
- Getting stuck on beaches that cannot take the weight of the vehicle.

Training required to operate the vehicle.

The self-propelled harvesting vehicle is most effective for cleaning up large-scale strandings.

4.2.4.4 Mechanised onshore seaweed collection: Excavator

Various public works companies and municipal councils undertook mechanised onshore collection operations using an excavator.

Five operations were evaluated:

Date	Municipality	Site
24/04/2018	LE DIAMANT	Anse Cafard
04/05/2018	LE DIAMANT	Anse Cafard
09/05/2018	LE ROBERT	Pointe Savane
17/05/2018	SAINTE-ANNE	Anse aux bois
20/06/2018	LE FRANCOIS	Frégate Est 2

4.2.4.4.1 Labour requirements

During the evaluation exercises, on-site staffing was limited to 1 driver for the excavator and one or more drivers for the tipper trucks.

4.2.4.4.2 Equipment requirements

The excavator is a piece of heavy construction machinery, also known as a digger or long-reach excavator.

Excavators comprise a chassis on caterpillar tracks or tyred wheels topped with a cabin that rotates 360 degrees. The cabin also holds the engine, hydraulic lifting gear (pump, motor, cylinders), the driver's seat and equipment (arm, boom, swinging arm and bucket).

Figure 71: Long-reach excavator

Excavators come in all sizes but can be split into 4 categories:

- Mini-excavators (under 10 tonnes).
- Medium excavators (10 - 30 tonnes), the type of model used for these trials.
- Large excavators (30 - 100 tonnes).
- Mining or "production" excavators (> 100 tonnes).

Similarly, their buckets come is a wide range of shapes and forms. The buckets observed for the trials were:

- Digging buckets;
- Riddle buckets.

Figure 72: Digging bucket (left) and riddle bucket (right)

4.2.4.4.3 Seaweed collection arrangements

In contrast to the previous methods, having a long-reach excavator on-site means you can load tipper trucks directly, with no need to move, apart from a simple rotation of the cabin. The collection cycle for a long-reach excavator is very stable as the machine does not need to move.

The average time recorded for a cycle, including filling the bucket, rotating the cabin to the tipper truck, emptying it and returning to the stranding is **approx. 35s.**

4.2.4.4.4 Estimated yield

The yield can be rapidly estimated based on the size of the bucket and the average cycle time: for a 1 m^3 bucket, this amounts to a theoretical yield of about 100 m^3/h.

During the trials, we recorded loading speeds for tipper trucks with known volumes.

Table 8: Data summary – Self-propelled vehicle

Site	Le Diamant Anse Cafard	Le Diamant Anse Cafard	Le Robert Pointe Savanne	Sainte Anne Anse Aux Bois	Le François Frégate Est 2
Weather conditions	Good	Good	Good	Good	Good
Bucket type	Digging bucket	Digging bucket	Riddle bucket	Digging bucket	Riddle bucket
Average thickness (m)	0.8	0.4	0.5	1	-
Extent of coverage	100%	95%	100%	100	Bay end collection
Seaweed stranding date	<48h + >48h	<48h	<48h + >48h	<48h + >48h	-
Average filling time for 15 m3 tipper truck (s)	270	375	540	535	-
Average filling time for 20 m3 tipper truck (s)	360	540	420	-	438
Average filling time for 24 m3 tipper truck (s)	400	600	-	-	-
Overall yield in m^3 per hour	215	140	135	100	165
Easy to gather?	Yes	Yes	Yes	Yes	Yes

Given these figures, we can say that:

- Collection yields are high (> 100 m^3), averaging 150 m^3 per hour
- No particular difficulties were noted when using a long-arm excavator

Figure 73: Before and after (3h 20m) (Anse Cafard – Le Diamant)

4.2.4.4.5 Costs

The costs are taken from bibliographic references and feedback:

- **Daily hire fee**:
  - Long-reach excavator + driver + maintenance €2,000 per day

In optimal circumstances, the best possible yield for the set-ups tested is roughly 150 m^3/h.

This would correspond to a cost price of around €2.6 per m^3 harvested, based on the assumption of 5 hours working on-site. Given that 1 m^3 of fresh, wet *Sargassum* seaweed weighs an average of 300 kg, the average cost is €7.8 per tonne.

In sub-optimal conditions (60% of the optimum yield), the average yield is about 90 m^3 per hour.

This would correspond to a cost price of around €4.5 per m^3 harvested, based on the assumption of 5 hours working on-site. Given that 1 m^3 of fresh, wet *Sargassum* seaweed weighs an average of 300 kg, the average cost is €13.5 per tonne.

In non-optimal conditions (30% of the optimum yield), the average yield is about 45 m^3 per hour.

This would correspond to a cost price of around €9 per m^3 harvested, based on the assumption of 5 hours working on-site. Given that 1 m^3 of fresh, wet *Sargassum* seaweed weighs an average of 300 kg, the average cost is €27 per tonne.

These costs do not include those related to returning sand gathered from the site. An estimation of the cost of returning sand to replenish a beach is given in section 4.4.

Long-reach excavators can load seaweed directly into tipper trucks without the need for an intermediary stage.

Figure 74: Directly loading a tipper truck

4.2.4.4.6 Evaluation of strengths and weaknesses

Type of impact	Comments	
Yield	Theoretical yield of 100 - 200 m^3/h in optimal conditions. Yield is highly dependent on: ○ Bucket size ○ Tipper truck capacity to perform rotations, as any hold-up in the flow will result in a net loss in collection yields.	
Optimal thickness (m)	No max. limit.	-
Fresh seaweed clean-up capacity (<48h)	Very good	
Old seaweed clean-up capacity (>48h)	Very good	
Effect on beach erosion	Collecting seaweed with long-reach excavator buckets has a major impact on beach erosion as this method is not selective. Sand amounting to 20 - 40% of total volume collected was recorded. Beach erosion has many negative effects (see section 4.2.1.2, p51)	
Beach load bearing capacity (formation of ruts, bogging down)	Excavators are fitted with caterpillar tracks so they can be used on beaches with lower load bearing capacities. The downside is they need to be near tipper trucks to collect and dispose of seaweed but the beaches cannot easily take the weight of these trucks.	
Risk of crushing sea turtle nests and vegetation	Yes, in the case of movements on the upper part of the beach. Care must nevertheless be taken when manoeuvring the excavator.	 
Mobility (excl. load bearing capacity)	Excluding the collection stage, long-reach excavators have good mobility on-site but are immobile when they gather seaweed without causing considerable drop in yield.	 
Workers' health and safety	Driver safety equipment and good working conditions (elevated cabin, H_2S detector, air-conditioning)	

It should be noted that during the trials, the riddle bucket tested did not show itself to be particularly effective; the time taken to empty a bucket full of water only is 46 seconds by tipping the bucket to ensure water drains through all the holes. In fact, as the time to fill and empty a bucket was less than 20 seconds, there was no time to empty the riddle bucket, especially as when full the tilted bucket restricts the number of holes for the water to run out of.

Figure 75: Mix of sand and *Sargassum* from beach clean-ups using long-reach excavators

The amount of sand observed during the clean-up operations varied considerably, averaging 20 - 30% of the total amount collected.

4.2.4.4.7 Areas for improvement

The main areas for improvement with this method are:

- **The use of more appropriate buckets**: Digging and riddling buckets cause considerable beach erosion. It would be useful to test other buckets that may be possibly better suited to beach cleaning, such as screening, grapple or claw buckets, etc.

Figure 76: Examples of screening or claw buckets

4.2.4.4.8 Conclusions

Key points to note

Excavators are mechanised onshore and shoreline seaweed collection tools.

They deliver high collection yields (100 - 200 m^3/h) regardless of stranding type.

This collection method nevertheless constitutes one of the main source of beach erosion and, as such, has maximum impact on the environment when using digging or riddle buckets.

Special attention must be given to:

- Good tipper truck rotations to ensure a skip is always present next to the excavator;
- The ability of tipper trucks to access stranding sites on low load-bearing beaches;
- Storage traceability of removed sargassum to recover and return the sand to the right site, as required (replenishing beaches)

Training required to operate the vehicle.

Currently, the use of long-reach excavators with digging or riddle buckets should be avoided as much as possible due to their heavy environmental impact (erosion). These techniques nevertheless make it possible to work on areas inaccessible to other methods from the land (backs of bay, shorelines, etc.) and are suited to mass, well-rotted seaweed strandings.

4.3 Collection assistance

4.3.1 Mechanised collection assistance: Beach groomer

The EEN Company was tasked with undertaking seaweed collection assistance trials using a beach groomer.

The operation was evaluated on:

Date	Municipality	Site
10/08/2017	SAINTE ANNE	Anse aux bois

4.3.1.1 Presentation of equipment

4.3.1.1.1 Labour requirements

During the evaluation exercises, on-site staff present included:

- 1 driver

Ultimately, the system only requires one person.

The beach groomer is a tool to assist seaweed collection operations that is hooked up to a harvester (long-reach excavator, etc.)

4.3.1.1.2 Equipment requirements

The beach groomer is a towed piece of machinery and has teeth mounted on springs to comb the beach surface to gather objects lying on it.

Figure 77 : Beach groomer

The main features are shown below (manufacturer's data):

- Pulling power: 4x4 agricultural tractor (80 cv minimum);
- Tyres: low-pressure high load-bearing;
- Length: 2 m;
- Height: 1.45 m;
- Total width: 2.5 m;
- Operating width: 2.4 m;

- Weight: 750 kg;
- Number of teeth: 28 retractable;
- Average speed: 20 km/h

The beach groomer also has two side deflectors to prevent objects raked up from escaping.

The tractor driver's cabin is air-conditioned and has an H_2S gas detector. The beach groomer requires just one driver.

4.3.1.2 Seaweed collection arrangements

The beach groomer does not collect seaweed but rather assists seaweed collection. It must be connected to a second harvesting tool, such as a digger, excavator) to improve their yields.

4.3.1.3 Estimated yield

The beach groomer simplifies seaweed collection using other methods by forming piles or moving seaweed about the beach.

As such, no direct yield and can be estimated using this method.

4.3.1.4 Costs

The costs have been taken from data provided by AXINOR and ADEME (prices as of March 2015 and subject to change)

- **Material investment cost** (excl. tax): €9,000 - 10,000

- **Day hire fee**: Not communicated

4.3.1.5 Value for money

As the yield could not be analysed, value for money for this method cannot be defined with the available data.

4.3.1.6 Evaluation of strengths and weaknesses

Type of impact	Comments	
Yield	**Does not collect**	
Optimal thickness (m)	Insufficient trials	-
Fresh seaweed clean-up capacity (<48h)	Not observed	
Old seaweed clean-up capacity (>48h)	Equipment breaks after a few metres	
Effect on beach erosion	The teeth lift a lot of sand when mixed with surface seaweed	
Beach load bearing capacity (formation of ruts, bogging down)	High sensitivity for the tractor despite the use of low-pressure, high load-bearing tyres.	 
Risk of crushing sea turtle nests and vegetation	Yes, in the case of movements on the upper part of the beach. Care must nevertheless be taken when manoeuvring the excavator.	 
Mobility (excl. load bearing capacity)	Not observed.	
Workers' health and safety	Driver safety equipment and good working conditions (elevated cabin, H_2S detector, air-conditioning)	

4.3.1.7 Conclusions

Key points to note

From observations made during trials, the beach groomer does not appear to deliver significant improvements when dealing with large strandings. Indeed, thick layers of seaweed that cause health and environmental problems are already sufficiently gathered together to be harvested by other methods. Additionally, the teeth lift large amounts of sand which combines with the seaweed when raking the beach. This adds weight to tipper truck loads and exacerbates erosion processes.

The beach groomer appears better suited for use on scattered strandings where the goal is to make beaches visibly cleaner. This last scenario has not yet been tested.

4.3.2 Mechanised collection assistance: Amphibious harvester

4.3.2.1 Presentation of equipment

4.3.2.1.1 Labour requirements

During the evaluation exercises, on-site staff presence was limited to:

- 1 driver
- 1 companion

The amphibious harvester is designed to assist seaweed collection and must be connected to a collector, such as an excavator, etc.

4.3.2.1.2 Equipment requirements

The amphibious harvester is a versatile vehicle that can work on land or at sea (close to the shore). It has a simple seaweed harvesting tool at the front (fork or bucket) and guides floating seaweed to a collection point within reach, e.g. an excavator. It does not store or directly dispose of seaweed.

Figure 78: Amphibious harvester

4.3.2.2 Seaweed collection arrangements

The TRUXOR itself does not collect seaweed but assists collection operations. It must be connected to a second harvesting tool, such as a mechanical digger or long-reach excavator, to improve their yields.

4.3.2.3 Estimated yield

Strictly speaking, the TRUXOR is not a collection tool because it does not pick up seaweed. Instead, it is designed to simplify seaweed harvesting operations using other methods by moving floating seaweed towards a collection point.

As such, no direct yield and can be estimated using this method.

4.3.2.4 Evaluation of impacts

Area	Type of impact	Comments	
HEALTH	Workers' health and safety	Driver safety equipment and good working conditions (elevated cabin, H2S detector, air-conditioning)	
ENVIRONMENT	Beach erosion	The TRUXOR mainly operates on water, while the beach is only used to launch and recover the vehicle. Its caterpillar tracks spread the vehicle's load over a larger surface area to reduce the risk of erosion.	
	Crushed vegetation	The vehicle's movements on the beach contribute to vegetation being crushed. Care must be taken when manoeuvring the TRUXOR.	
	Impacts on sea turtles	Although clean-ups are carried out during the day, the risk of running over an adult or juvenile turtle still exists, as does the danger of crushing their nests. Unfortunately, this risk cannot be quantified as the use of a real sea turtle nest is not possible. The use of caterpillar tracks does lessen this risk as the weight is spread over a larger surface area. Care must nevertheless be taken when manoeuvring the excavator.	 
	Marine environment impacts	The TRUXOR's movements are unlikely to cause disturbance, particularly to marine environments as it operates with a shallow draft, staying close to the shoreline.	

4.3.2.5 Conclusions

Key points to note

Given its features, the TRUXOR appears to be better suited to areas where onshore collection is complicated by a lack of space or difficulties to manoeuvre heavy machinery. Its role is to guide seaweed towards to a collection area operated by another collection method (long-reach excavator).
This type of equipment must be combined with an additional collection method.

4.4 Transportation

Tipper trucks are currently used to take the seaweed away from stranding areas.

Estimated disposal costs are between €5 and €10 m³/km[7], assuming a load of 300-350 kg/m³, or approx. €15 - 30 t/km. T**his cost applies to all collection techniques and includes**:

- The provision of one or more tipper trucks.
- The cost to load the trucks.
- Transport costs (if not included in the cost of providing tipper trucks).
- Possible handling costs by the receiver organisation.

Key points to note

The estimated disposal cost for sargassum seaweed is €5 - 10 m³/km, or approx. €15 - 30 t/km for fresh seaweed.

A cost can also be estimated for returning sand collected when highly erosive heavy machinery is used to gather the *Sargassum* (long-reach excavator with digging bucket, or loader, etc.).

This is based on the assumption of using:

- A 13 t long-reach excavator to load the sand: approx. €600/day
- An 11 m³ tipper truck to transport the sand: approx. €500/day
- A 12 - 18 t loader to reinstate the sand on the beach: approx. €900/day
- 20 % business expenses
- 6 round-trips per day by tipper truck, or approx. 1 per hour. (i.e. 66 m³/day)

The estimated cost subsequently amounts to €2,400/day for 66 m³, corresponding to €36/m³ of sand. This estimated cost depends on the number of possible rotations in a day (varies based on distance and loading/discharging time), number of tipper trucks used (a second truck optimises costs if sand reserves are large enough: approx. €23/m³ of sand) plus the price of equipment hire.

Key points to note

Using the previous assumptions*, the estimated cost of returning sand to the beach can be* ***€20 - 40/m³.*** This cost excludes any eventual preliminary studies or specific beach nourishment schemes.

[7] François COLAS-BELCOUR, Tristan FLORENNE, François GUERBER (July 2016), "*Le phénomène d'échouage des Sargasses dans les Antilles et en Guyane*", CGEDD Report No. 010345.

5 SUMMARY

5.1 Observation remarks

The observations made suggest that **the ideal solution to collect *Sargassum* seaweed in terms of its environmental impact is near shore collection**. Using this collection method involves:

- **Pairing up with offshore barrier** systems, for which there is still too little information. Barriers can be subjected to excessive forces such as swells and dense mats of Sargassum) that can cause them to split. Their maintenance requirements plus the need to rapidly install and dismantle them if hurricane warnings are issued is a problem if they are deployed in long lengths or from multiple points. This aspect is a particular hindrance as it needs a large workforce available to work on numerous barriers, or if this labour is likely to be allocated to other tasks (e.g. to protect property).
- **Improvements must be made to equipment storage (volumes) and transport (time) issues** as these two factors restrict yields.

In terms of onshore collection, **the use of high-impact methods such as long-reach excavators and front loaders with digging or riddle buckets must be expressly avoided**. Although they can deliver high yields and seem cost-effective, these methods are highly erosive to beaches. Indeed, based on observations made on-site, 20 – 30 % of the average amount collected is sand. This causes a whole host of problems and ultimately exacerbates *Sargassum* stranding events (increasing the surface area for strandings by narrowing beaches, reducing their load bearing capacities and their disappearance, etc.). As a result, returning sand to beaches as part of beach nourishment initiatives can be costly.

Using such aggressive methods must be limited to areas that are inaccessible to other options.

Using appropriate buckets on heavy machinery can also be part of the solution to this problem.

A combination of beach grooming and self-propelled collection vehicles appears to offer a better impact/efficiency ratio:

- The self-propelled vehicle can clean up thick mats of seaweed and leaves a thin layer on the beach.
- The beach groomer can collect this layer while not getting clogged up with too dense beds of seaweed. The groomer can also be regularly used as a beach maintenance tool.

That said, these methods must be used quickly, in less than 48 hours after mass strandings to prevent seaweed from rotting and compacting, which could make collection difficult.

A comparison chart to assess the various methods observed is shown below.

5.2 Inter-method evaluation chart

Field	Method	Overall yield (excl. removal) in optimal (100%), sub-optimal (60%) and non-optimal (30%) conditions (m^3/h)	Estimated collection costs (excl. removal) in m3 according to yield: optimal (100%), sub-optimal (60%) and non-optimal (30%)	Optimal thickness (m)	Undecomposed stranding/mat capacity (<48h)	Decomposing stranding/mat capacity (>48h)	Effect on beach erosion	Risk to wildlife (sea turtle nests, aquatic species)	Load bearing capacity susceptibility	Collection mobility	Operator health and safety	Role of method
Manual onshore collection	Green Brigade/RSMA	2 - 3 m^3/h/person	10 / 17 / 35	>0.1								Beach cleaning and clearing small strandings of fresh seaweed
Mechanised onshore clean-up	Surf rake (SEEN)	Approx. 40 m^3/h	8 / 14 / 27	<0.3 m								Beach cleaning and clearing small strandings of fresh seaweed
	Self-propelled harvesting vehicle (AXINOR)	90	9 / 18 / 33	0.2 - 0.8 m								Mass strandings
	Long-reach excavator (public works companies, municipalities, DEAL)	150 m^3/h	2.6 / 4.5 / 9 ***(Not including costs to return the sand to the beach)***	>0.5 m			*(digging/riddle bucket)*					Mass strandings unable to be collected by other less harmful techniques
	Cane loader	30 – 125 m3/h	1.2 / 5	>0.5 m								Mass strandings
Mechanised offshore collection	Offshore harvesting barge (ALGEANOVA)	Approx. 30 m^3/h	*No day hire fee*	-					n/a			Near-shore collections
	Small harvesting barges (Sargator, Lougarou)	8 - 19 m^3/h	*No day hire fee*	-		Not observed			n/a			Near-shore collections
	Trailing suction hopper dredger (ELBE)	***Insufficient and inconclusive trials***	-	-		Not observed			n/a			Offshore collection
	Mobitrac amphibious suction vehicle ***Work in progress on the method***	2-3 m^3/h ***Work in progress on the method***	***Work in progress on the method***	-					n/a			Bay end collection
	Crane operation	Fresh seaweed collection not observed. 20 t/day when	*No day hire fee*	-	Not observed							Bay end collection

		raking the seabed										
	Offshore harvester (SOTRADOM) ***Method not operating at time of tests***	Not observed	-	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Near-shore collections
	Harvesting conveyor	Not observed	-	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Not observed	Bay end collection
Collection assistance	TRUXOR amphibious vehicle	-	-	-	 ***Does not collect***	 ***Does not collect***					 	Helps collect seaweed near to the shore
	Beach groomer ***Method not operating at time of tests***	-	-	-	Not observed ***Does not collect***	 ***Does not collect***		 	 	Not observed		Collection assistance

5.3 Decision tree

A method can be also chosen using a decision tree by considering various scenarios then selecting one or more methods suited to the type of stranding and the site to be cleaned up.

An example of a decision tree is shown below.

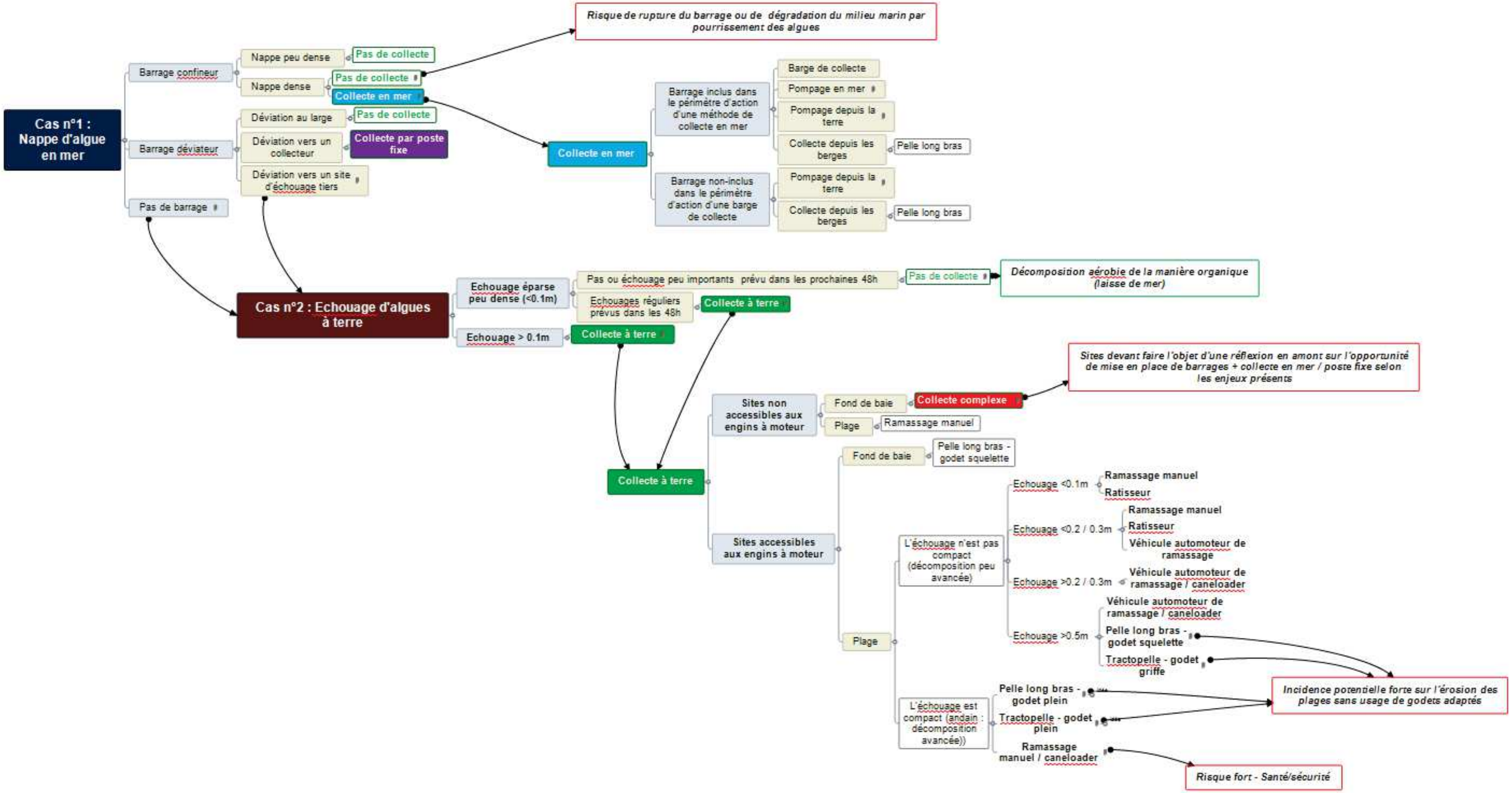


Figure 79: Decision tree

Case 1

<table>
<tr><td rowspan="12">Case 1: offshore mat of seaweed</td><td rowspan="8">Containment barrier</td><td>Light mat</td><td>Don’t collect</td><td></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="8"></td><td rowspan="8"></td></tr>
<tr><td rowspan="7">Dense mat</td><td>Don’t collect</td><td>Risk of barrier splitting or damage to marine environment by rotting seaweed</td></tr>
<tr><td rowspan="6">Collect offshore</td><td rowspan="6">Collect offshore</td><td rowspan="4">Barrier within the operational area of an offshore collection method</td><td>Harvesting barge</td><td></td></tr>
<tr><td>Offshore pumping</td><td></td></tr>
<tr><td>Shore-based pumping</td><td></td></tr>
<tr><td>Collection from harvesting barges</td><td>Long-reach excavator</td></tr>
<tr><td rowspan="2">Barrier outside harvesting barge operational area</td><td>Shore-based pumping</td><td></td></tr>
<tr><td>Shoreline collection</td><td>Long-reach excavator</td></tr>
<tr><td rowspan="3">Diversion barrier</td><td>Divert offshore</td><td></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Divert to harvester</td><td>Collect using a stationary harvester</td></tr>
<tr><td>Divert to separate beaching site</td><td></td></tr>
<tr><td>No barrier</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Case 2

<table>
<tr><td rowspan="3">Case 2: Seaweed strandings</td><td rowspan="2">Scattered, light beached seaweed (less than 0.1 m thick)</td><td>No large strandings or barely any expected in next 48 h</td><td>Don’t collect</td><td>Organic aerobic decomposition (debris lines)</td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Regular strandings expected in next 48 h</td><td>Collect</td><td></td></tr>
<tr><td>Beached seaweed over 0.1 m thick</td><td>Onshore collection</td><td></td><td></td></tr>
</table>

Onshore collection	Sites inaccessible to motorised machinery	Bay heads	Complex collections	Sites having been previously assessed on possibility to install barriers + offshore collection/stationary harvester subject to challenges present on-site			
		Beaches	Manual collection				
	Sites accessible to motorised machinery	Bay heads	Long-reach excavator – screening bucket				
		Beaches	Beached seaweed not compact (early stages of decomposition)	Beached seaweed less than 0.1 m thick	Manual collection		
					Surf rake		
				Beached seaweed less than 0.2/0.3 m thick	Manual collection		
					Surf rake		
					Self-propelled harvesting vehicle		
				Beached seaweed over 0.2/0.3 m thick	Self-propelled harvesting vehicle/Cane loader		
				Beached seaweed over 0.5 m thick	Self-propelled harvesting vehicle/Cane loader		
					Long-reach excavator – screening bucket	High likelihood of beach erosion without using appropriate buckets	
					Mechanical digger – claw bucket		
			Beached seaweed is compact (bands of well-rotted seaweed)	Long-reach excavator – digging bucket			
				Mechanical digger – digging bucket			
				Manual collection/Cane loader		High health and safety risk	

APPENDIX 1 " EXPOSED WORKERS PROTECTION GUIDE: GREEN ALGAE" CEVA

Exposed workers protection guide:

algues vertes

Green algae

March 2012

foreword

This guide has been produced by a regional working group for occupational risk prevention. The working group was established in 2006 and has drafted a series of annually reviewed recommendations for local authorities and private companies involved in various stages of clean-up, transportation and treatment operations for decomposing seaweed.

Its aim is to protect exposed workers.

This document is intended to be used directly by local authorities when directly undertaking clean-up operations or for inclusion in future public procurement exercises, to be applied by the contracted service providers.

Note to the reader

This guide comprises a main report featuring prevention principles applicable irrespective of working conditions and several practical information factsheets providing all necessary details on prevention measures to be taken for a given set of working conditions (e.g. Practical information sheet 1: Mechanised collection of fresh seaweed).

Please refer to the main report before viewing the practical information factsheets.

This guide can be downloaded from the Direccte Brittany website:
www.bretagne.direccte.gouv.fr

con tents

Practical information

Templates

green algae
in Brittany

Conditions for the proliferation of green algae

SOURCE bretagne-environnement.org

The green tides that affect the Brittany coastline stem from a huge proliferation of Ulva-type green algae. Green tides grow predominantly from drifting algae propagating in spring and summer.

The green algae blooms are due, in particular, to excessive quantities of nutrients in seawater, especially nitrates and phosphates. This is a specific form of pollution called "eutrophication".

The main culprit is nitrates

Although ulva seaweeds also need phosphorus as well as nitrates to grow, only the latter currently controls their reach. Indeed, in areas hit by green tides, there is always more phosphorus stored in sediments in the bays than the ulva seaweed needs to grow. The extent of green tides therefore depends on a continuously high supply of nitrates during the ulva growing season (spring and summer).

Geographical and environmental conditions favouring green algae growth

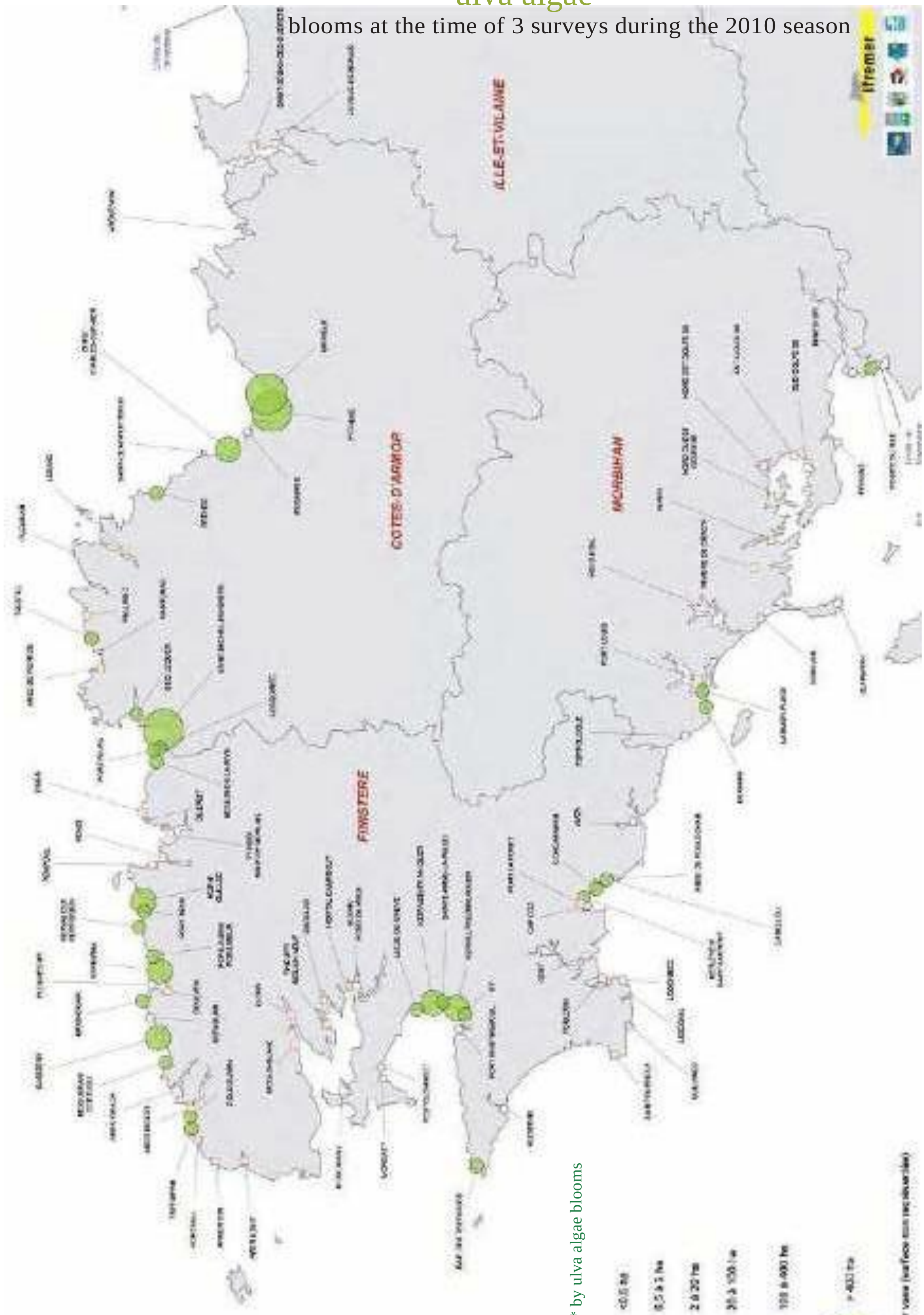
Nitrate discharges alone are not enough to fuel such huge blooms of green algae and subsequent beachings. In fact, there must be a combination of geographical and environmental conditions for this to happen:

- long periods of high light intensity (peaking in spring),
- seawater temperatures above 13-14°C,
- high water clarity,
- large stretches of foreshore providing extensive areas for deposition,
- trapped water masses and nutrient-rich salts that help grow and sustain biomass in areas conducive to algae growth,
- specific winter weather and sea conditions.

> In Brittany, green tidal zones are always on coastlines close to river mouths, either on mudflats, or wide, gently sloping sandy bays with shallow water that heats up easily and where light can penetrate.

Surface areas covered by cumulative ulva algae

blooms at the time of 3 surveys during the 2010 season



Approximations in the P112 military area (not overflown)

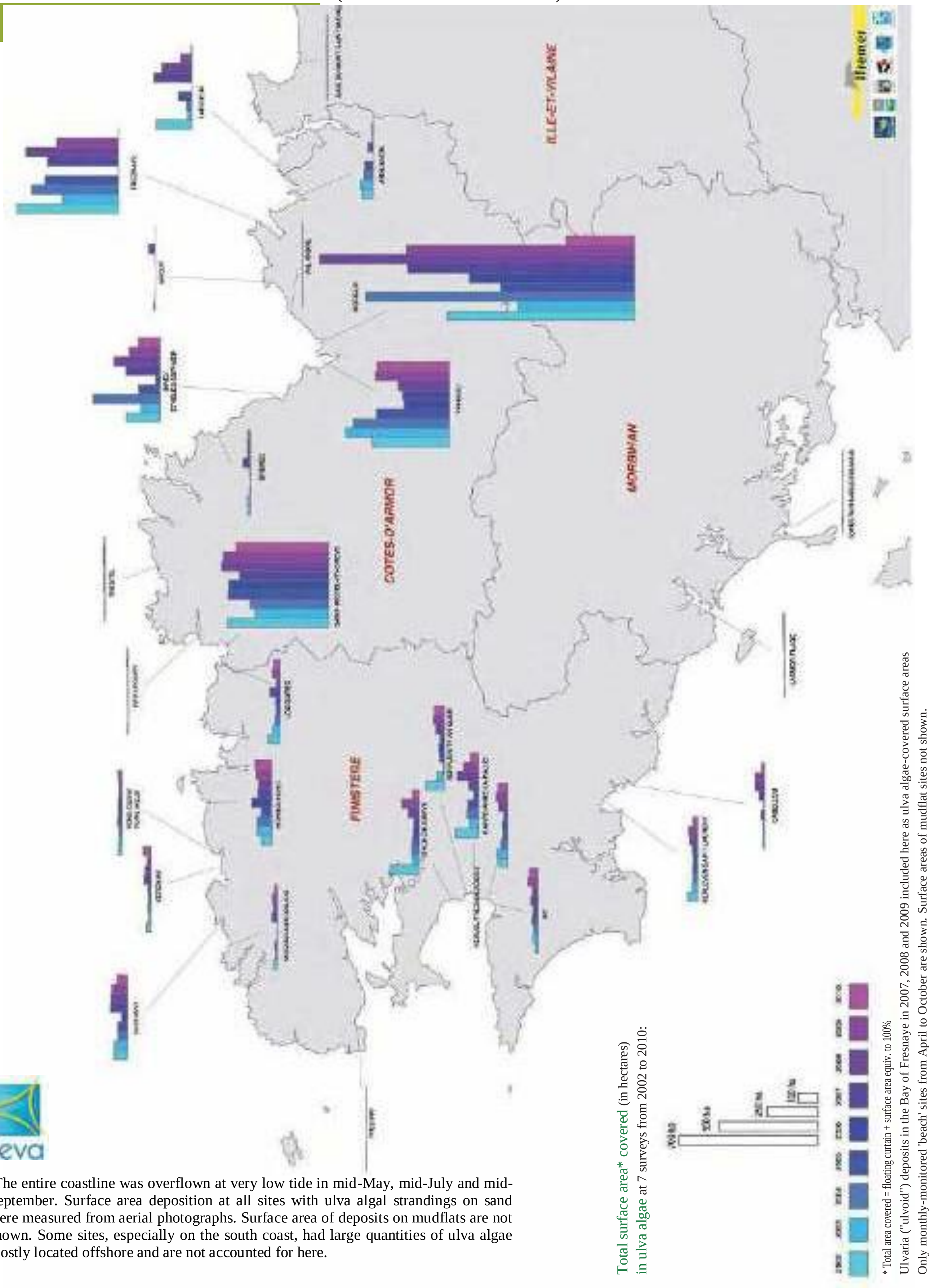
Surface areas covered* by ulva algae blooms in 2010

* Total area covered = floating curtain area + foreshore deposits equivalent to 100% coverage

The entire coastline was overflown at very low tide in mid-May, mid-July and mid-September. Surface area deposition at all sites with ulva algal strandings on sand were measured from aerial photographs. Ulva algae deposition surface areas on mudflats are not shown on the map. Some sites, especially on the south coast, had large quantities of ulva algae mostly located offshore and are not accounted for here.

Geographical areas affected

Variation of ulva algal strandings at key sites between 2002 and 2010 (combined annual totals)



The entire coastline was overflown at very low tide in mid-May, mid-July and mid-September. Surface area deposition at all sites with ulva algal strandings on sand were measured from aerial photographs. Surface area of deposits on mudflats are not shown. Some sites, especially on the south coast, had large quantities of ulva algae mostly located offshore and are not accounted for here.

Exposure-related risks

Potentially hazardous chemical compounds

Various studies[1] have shown the existence of risks from exposure to potentially hazardous chemical compounds given off by decomposing green algae. These risks concern clean-up workers collecting, transporting and treating algae.

Hydrogen sulphide (H_2S) is of greatest concern among these chemical compounds.

H_2S is a colourless gas which is heavier than air and has a characteristic foul smell. Its presence is an indicator for other related chemical compounds, which are more difficult to identify, so it serves as a tracer.

H_2S produced by green algae is directly linked to anaerobic fermentation.

This invariably concerns algae that has been washed ashore for more than 48 hours, especially if it is piled to over 10 cm deep or if it rots underneath a hard, dry crust.

Site topography, atmospheric temperature coupled with the presence of fresh water (streams and pockets of water, etc.) and soils containing lots of decomposed organic matter constitute parameters likely to cause H_2S levels to vary and how quickly it appears.

Mudflats, where algae combines with sediments at every tide also present a hazard scenario, even more so given that the algae is not visible to the eye.

Risks for persons exposed to green algae

- Effects from hydrogen sulphide (H_2S), one of the most dangerous gases.

  Hydrogen sulphide is a rapidly acting toxic gas for humans. Depending on different levels of exposure, H_2S can be lethal or result in a loss of consciousness followed by coma and/or irritation to eye and respiratory mucous membranes. Repeated exposure can also result in chronic bronchitis.

- In certain conditions, airborne concentrations of H_2S can exceed exposure limits (set at 10ppm or 14mg/m^3 for 15 minutes) and the average exposure limit (set at 5ppm or 7mg/m^3 over a period of 8 hours).

Examples of readings taken:

- for thick deposits (more than 5 days old, frequent at the start of the season, or stagnant blooms in fresh water, rainwater or streams): more than 500 ppm
- Clean-up worker positioned downwind, moving piles of green algae:
  250 ppm or above

- The presence of ammonia (NH_3), often related to H_2S, adds to the effects of the latter when there are large quantities of algae. Various sulphur-based compounds have milder effects which have yet to be assessed.
- Substances present in algal fermentation fluid can also cause severe skin or mucous membrane irritation.

1 CEVA report for the DDASS 22 dated 28/04/07 www.ceva.fr
INERIS study report dated 19/08/09 www.ineris.fr – ANSES report, July 2011 www.anses.fr

prevention
procedure

Green algae exposure constitutes a chemical exposure risk.

The steps to follow are:

1. organise medical checks by an occupational health physician, or risk prevention specialist for exposed persons
2. check to see that no counter-indications from wearing personal protective respiratory equipment arise
3. carry out a risk assessment for each worker to ensure their level of exposure can be traced. This information must then be sent to the occupational health physician or prevention specialist.

The outsourcing organisation must assess the risks

identify the hazards
analyse the risks
define preventive measures
organise an audit of exposed persons and introduce a system to monitor them

The outsourcing organisation must adopt general prevention measures as defined in Article L. 4121-2 of the French Labour Code.

As such, clean-up contractors must make the following minimum necessary provisions:

■ Collect algae while they are still fresh: i.e. within 24 hours after beaching, to not exceed a 48-hour time limit between collection and treatment.

If algae is stored temporarily: The outsourcing organisation must make safe the site in compliance with applicable statutory provisions (available for consultation with the relevant services referred to in this document).

This involves, in particular:

- signage for piles of algae;
- the display of health and safety information;
- a general public exclusion zone at least 30 m around the algae;
- the choice of sites far from residential areas and public passageways;
- ensuring uninterrupted and secure access to heavy machinery for collecting and transporting algae;
- not contaminating the soil by fluids collecting from piles of algae stored temporarily on a regular basis.

In all cases, a 48-hour deadline applies from collection to treatment and should be checked by the outsourcer to its contractors.

- Limit manual clean-ups to a strict minimum by preferring mechanised collection methods, including partially, as soon as possible and by making all arrangements beforehand to allow for heavy machinery access.

- Prioritise preventive measures based on the previously assessed exposure risk.

  Based on H_2S levels present estimated at the time of the clean-up, the most suitable prevention methods should be identified for:

  - the operating method,
  - choice of protective equipment to be used,
  - team protection measures must always be prioritised over individual equipment, in compliance with regulations,
  - qualifications and training of clean-up operators in high-risk situations. Only specifically qualified companies and trained, protected clean-up workers can clean up algae strandings,
  - safety and emergency procedures in working areas.

- Provide overall coordination for all clean-up operators (including subcontractors):

  - ensure that every clean-up operator hands over their personal risk assessment document and a prevention plan or safety protocol for loading and unloading operations,
  - ensure that every clean-up operator has safety equipment,
  - ensure that every clean-up operator knows how to use all health and safety rules,
  - ensure that every clean-up company is fully committed to adopting safety regulations for their employees (training, protective equipment, medical checks, etc.) before stepping on-site, and especially for inexperienced members of staff,
  - ensure that clean-up workers have health and safety equipment and changing facilities close to clean-up areas,
  - ensure clean-up areas are signposted.

- Always ensure that each clean-up worker (gathering or driving heavy machinery) wears a H_2S gas detector. SEE WORKSHEETS

  The gas detector checks gas levels that the clean-up workers encounter to define the right preventive and reactive measures to be taken. Under no circumstances whatsoever can the detector constitute an item of personal protective equipment. It is only used to warn that a danger exists. It does not protect the clean-up worker.

- Ensure that each clean-up operation undertaken is tracked (collection, transportation, storage / treatment): This involves, in particular, the use of documents to identify volumes, in terms of their appearance and general content of deposits, sites, date and time of each clean-up operation and clean-up workers, etc. SEE TRACEABILITY DOCUMENT TEMPLATE

- Identify wind direction by installing a windsock or flag on the beach. The wind direction must be checked throughout the entire period of the clean-up and any changes recorded.

The outsourcer is advised to

- decide between cleaning up strandings themselves or outsourcing the work based on the risk assessment and allocating the most hazardous tasks to those contractors best qualified to manage such situations;

- establish multiannual contracts with private sector companies to enable them to make the sometimes costly investments in equipment but better adapted to the health and safety needs of their users. A multiannual contract ensures that investments made are sustained in the long-term.

- combine or coordinate efforts in the same geographical area (clean-up area, bay, etc.) to pool specific health and safety equipment and cut costs, especially for a loader with an activated carbon filter or a gas detector checking terminal. SEE WORKSHEETS

essentials before starting a clean-up

Recommendations based on H_2S exposure risk assessment

Any situation in which workers come into contact with green algae implies prior:

- training for supervisors from all clean-up organisations (outsourcers, private companies, etc.) and workers, regardless of seniority.

  Seasonal workers, temporary workers or staff on fixed-term contracts must be given rigorous safety training.

  Training courses must be tailored. For example, 2 sheets appended to this guide feature details on training provided by CEVA, developed in conjunction with prevention services.

- Devise a prevention plan and/or safety protocol between each company and outsourcer, specifying operational arrangements and preventive measures to limit risk exposure when undertaking joint activities.

  This document outlines, among other things, actions to be taken when various alert levels are reached on the gas detectors used. Any other contractors working on the algae clean-up must also be made aware of the document.

- Organise work to ensure that no worker is ever left alone.

- Produce a workstation notice: This document is designed to inform those workers concerned about specific dangers related to the nature of the products they handle and to schedule a training session on how to use equipment, detection and protection devices (including protective overalls, boots, gloves, etc.).

- Clean-up area signage (cones, barriers, etc.) to mark a safety exclusion zone around clean-up operations.

  This area keeps all members of the public 30 meters away from all risks related to manoeuvring heavy machinery and H_2S exposure, especially for those without gas detectors or protective and safety devices. Emergency services access must also be planned.

useful

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  (training enquiries)

webs

for further reading

- French National Agency for Food, Environmental and Occupational Health and Safety .... www.anses.fr
- French Regional Health and Safety Agency .... www.ars.bretagne.sante.fr
- Brittany environmental observatory .... www.bretagne-environnement.org
- Algae Technology and Innovation Centre .... www.ceva.fr
- Direccte Brittany .... www.bretagne.direccte.gouv.fr
- French National Research and Safety Institute .... www.inrs.fr

Exposed workers protection guide:

This guide has been produced from research undertaken by the following bodies

ARS Brittany
French Regional Health and Safety Agency

ANSES
French national agency for food, environmental and occupational health and safety

CARSAT Brittany
French regional agency for occupational health and pensions
Occupational Risks Department

CEVA
Algae Technology and Innovation Centre

CDG 22
Côtes d'Armor regional civil service centre

CDG 29
Finistère regional civil service centre

CIRE Ouest
French public health monitoring "western" unit

Directte Brittany
Regional directorate for enterprise, competition policy, consumer affairs, labour and employment - Labour Unit

MSA Armorique
Agricultural Mutual Assistance Association

ORS Brittany
Regional health monitoring agency

Brittany occupational health department

This document has been published by Direccte Brittany

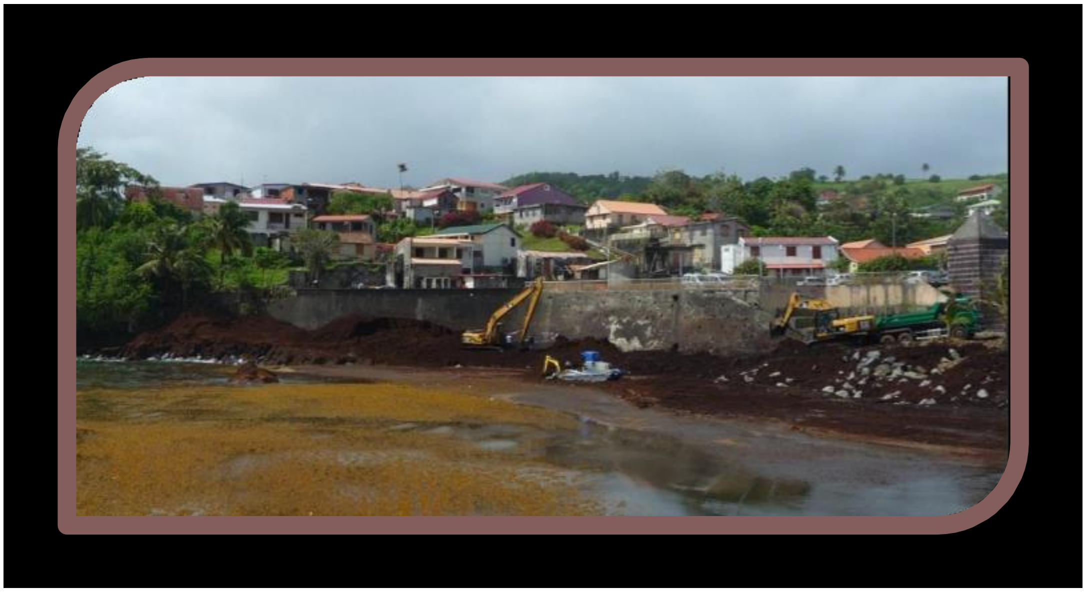
APPENDIX 2
" EVALUATION METHODOLOGY FOR EXPERIMENTS TO HARVEST SEAWEED" CEVA

Evaluation methodology for experiments to harvest seaweed

Summary

This methodological guide summarises key technical data to gather when evaluating seaweed harvesting methods. The guide supplements a related training programme. This guide does not refer to safety data for "beached seaweed" (especially hydrogen sulphide (H_2S) emission risks but this information must be disclosed to operators to apply the methods described in the present document.

Technical evaluation of a clean-up operation



2015

1. Contextualising the clean-up operation

1.1 Clean-up site description

The site description ultimately helps determine what types of techniques are best suited to a given site. It identifies how accessible the site is, its complexity, harvesting potential and the nature of the stranding.

Remember to take plenty of photos to illustrate your comments.

1.1.1 Site access

Site accessibility means the number of access points, type of access (slipway, direct access to the beach, path, etc.) and passageway width. These criteria can then help allocate the potential clean-up equipment for each site, to harvest seaweed.

1.1.2 Site complexity

Site complexity means any potential obstacles to harvesting operations on the site. These include, rip-raps, mangroves or protected sites right next to the harvesting area that require special clean-up arrangements.

1.1.3 On-site algal stock

An on-site assessment of the stock of seaweed must be made to then identify the harvesting method best suited to the site. This means making a rough estimation which doesn't require a great deal of accuracy. This assessment can be done in various ways depending on the stranding:

- Stranding which can be walked around: the clean-up operator plots out the stranding using a GPS device as they walk around the beached seaweed. The coordinates can then be exported to a geographical information system (GIS) to determine the surface area occupied by the seaweed.
- Stranding that cannot be plotted on-foot: The clean-up operator marks out the extent of the stranding by hand on a map. Next, this surface area is entered into a GIS to give a precise figure.

A coverage level can then be applied to the figure if the seaweed does not cover 100% of the area charted out on the map. Figure 1 provides an example.

Assumption: identified surface area = 1 ha

100% of the surface is covered by

60% of the surface is covered by seaweed

Seaweed surface area = 1 ha

Seaweed surface area = 1 ha * 60% = 0.6

Figure 1: Diagram of the method designed to estimate the surface area covered by seaweed

To assess the on-site seaweed stock, the algal biomass must be identified for the previously demarcated surface area. On the ground, the clean-up operator plots an area of seaweed representative of an average stranding situation using a quadrant (typically 0.25 m^2) All the seaweed present in the quadrant is removed with a net (Figure 2). If the layer of beached seaweed is too thick, only part of it can be removed (a quarter or half, for example). The net containing the seaweed is then immersed in water and hung up for 1 minute to drain the seaweed of water. After 1 minute, the seaweed is weighed by hooking the net to a portable set of scales. Re-immersing the seaweed in water before weighing them standardises the fresh weight measured on-site. This type of weighing technique should be undertaken at at least 3 different locations to calculate an average biomass value (drained kg 1 minute/m^2) correlated to a standard deviation. The sampling points must be recorded on a map. It is strongly advised to use a GPS device or at best, the clean-up operator must have a map to plot out the rough location of the sample.

The following formula is used to calculate the biomass:

$$\boxed{\text{Total biomass (kg)} = \text{av. biom. (kg/m}^2\text{) x tot surf. area (m}^2\text{) x cov. level. (\%)}}$$

- av. biom.: average biomass taken from weights recorded on-site
- tot surf. area: total surface area occupied by seaweed
- cov. level. : seaweed coverage level

Figure 2: **Illustration of a biomass measurement exercise on the beach using a 0.25 m^2 quadrant**

The same procedure can be used for floating seaweed, using a net with a known surface area (Figure 3).

Figure 3: **Image of a biomass measurement exercise on the beach using a 0.25 m^2 quadrant**

The following formula is used to calculate the biomass:

Total biomass (kg) = av. biom. (kg/m^2) x tot surf. area (m^2)

Seaweed generally collects in a homogeneous layer in the water regardless of how dense the layer is. Taking a direct measurement is therefore representative of the average situation and includes those areas where there is no seaweed.

1.1.4 Type of stranding

Strandings can be differentiated by the location (on the beach or in the water, the latter cannot be strictly termed a "stranding"), thickness and how fresh they are. Any observations can be added that provide additional information for safety requirements and environmental effects (typical rotten egg smell) linked to the presence of hydrogen sulphide (record the H_2S gas detector reading if a concentration is detected), brown/black fluid leaking from the seaweed, or the formation of a crust, etc.). Some examples can be seen in Figure 4.

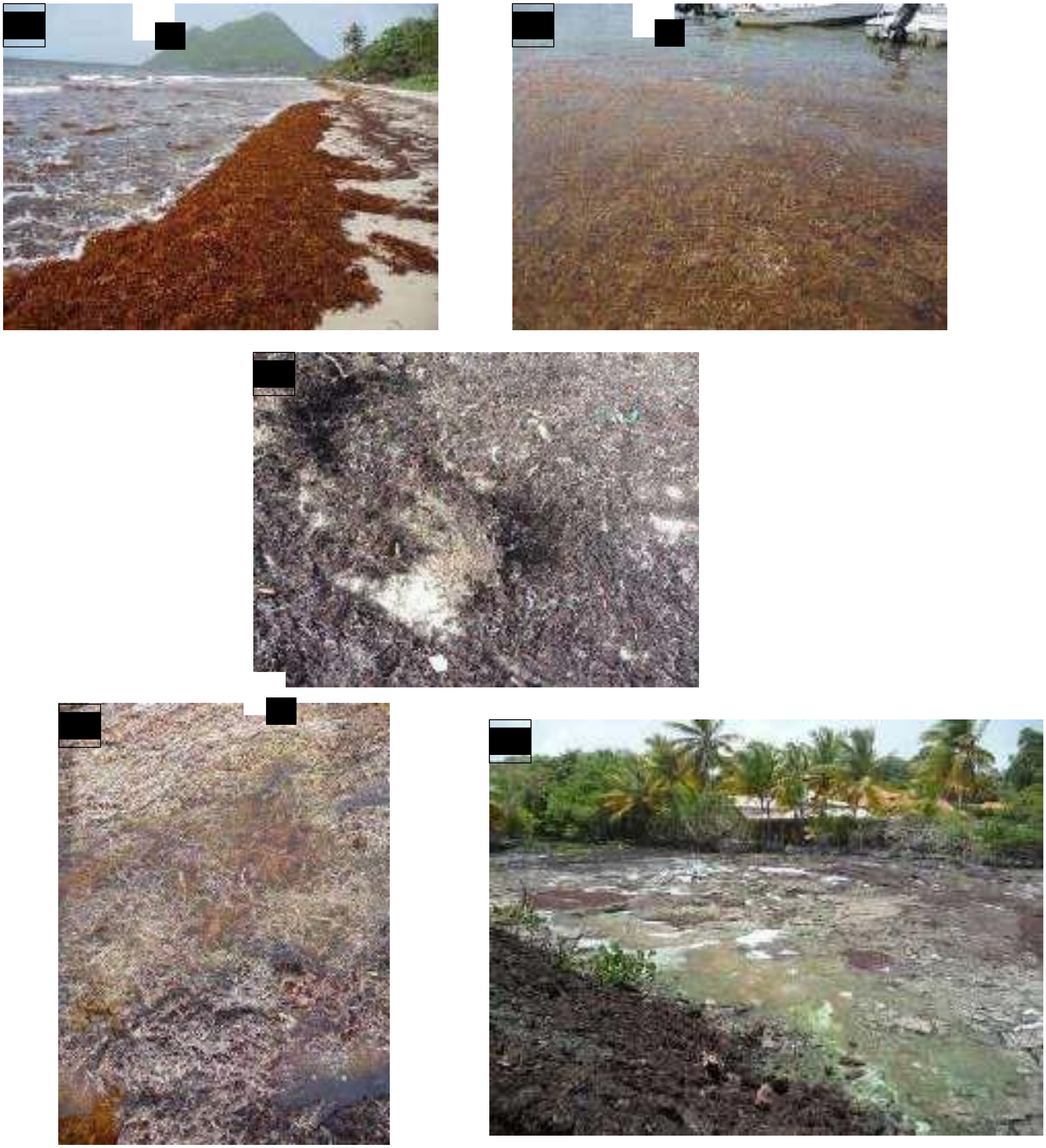


Figure 4: Photographs of various algal patterns present on the ground. 1- bank of freshly beached seaweed. 2- **Seaweed in water**, forming a consistent layer. 3- Dry seaweed. 4- Seaweed **in water mixed with fermented brown coloured fluid. Remember, walking in these types of algal deposits causes atmospheric H_2S concentrations to rise. 5**- Well-rotted seaweed, forming hard crusts. Keep back from **this type of algal deposit.**

1.1.5 Data compilation based on site description

Mapping is still the best way to describe a clean-up site. Also, if the clean-up operator has no GIS device or if they are unfamiliar with using one, several websites display maps which can be edited with polygons to estimate surface areas (Google Earth, Géoportail, etc.). Figure 3, for example, has been drafted using the Géoportail website (http://www.geoportail.gouv.fr/accueil).

Figure 5: Example of mapping to contextualise a clean-up operation. The red arrow indicates **the access point, the yellow-lined zone outlines the rip-rap area and the blue zone roughly indicates the area covered by sargassum.**

1.2 Description of equipment used

It is essential to record all kinds of information for evaluation purposes at each clean-up operation. This section will focus solely on seaweed harvesting systems without considering methods to remove the seaweed from the beach to treatment plants or land-based storage facilities.

Remember to take **plenty of photos to illustrate your comments**.

1.2.1 Harvesting method

State whether the harvesting operation is mechanised and/or manual.

1.2.2 Harvesting area

State if the seaweed is harvested on the beach and/or in the water. For harvesting in water, please state the water depth.

1.2.3 Harvesting tool

State whether a grapple-grabber or bucket, conveyor belt, surf rake, net, forks (for manual clean-ups), etc. has been used.

1.2.4 **Harvesting tool location**

State if the tool is positioned at the front, rear or sides of the machine used. Add, if applicable, if the tool is towed or pushed.

1.2.5 Harvesting equipment dimensions

The size of the equipment will vary according to the techniques used. For example, when using excavators, you must record the bucket width and volume. For conveyor belt techniques, you must note the belt width. For net techniques, the size of the net must be recorded.

1.2.6 Working depth/thickness

When harvesting in water, state the minimum and maximum working depths. When harvesting on the beach, state the minimum and maximum thickness of the beached seaweed so that the harvesting method is optimised. For example, if the layer of seaweed is thin, some techniques can remove large quantities of sand when harvesting. Conversely, when there are thick mats of seaweed, some techniques will leave the first few centimetres of seaweed.

1.2.7 Additional equipment/tools

State if there are additional facilities to supplement harvesting operations (e.g. a roller to pull the seaweed away from the surface) that shifts the seaweed immediately before removal (a press to remove the water) or to reduce the effects of harvesting operations (systems to avoid trapping fish, for example).

1.2.8 Seaweed storage

State if the machine used contains a storage facility for the seaweed (skip, hopper, etc.) and record the storage capacity (in m^3).

1.2.9 Seaweed transfer method

State the transfer method used to move the algae from the machine to a storage area on the beach. For example, some machines have a treadmill, or conveyor belt, to transfer harvested seaweed to a tipper truck.

1.2.10 Other features

State the power output of the machine, average fuel consumption, speed in conventional use (speed when not harvesting) and speed when harvesting. This type of information will be useful to assess the economic performance of the harvesting system.

All the aforementioned criteria are recorded in Table 1.

Table 1: Table summarising technical data to be gathered on-site to describe the type of equipment used

	Technique 1	Technique 2	...	Technique N
Harvesting method				
Harvesting area				
Harvesting tool				
Location of the harvesting tool				
Dimensions				
Working depth/ thickness				
Additional equipment/tools				
Seaweed storage				
Seaweed transfer				
Power (HP)				
Fuel consumption (l/h^{-1})				
Speed (when not harvesting)				
Speed (when harvesting)				

1.3 Description of clean-up operation organisational arrangements

1.3.1 Description of the various clean-up operation stages

A seaweed clean-up operation can include several stages:

- Harvesting stranded seaweed
- Transfer/unloading of harvested seaweed (to form piles at the rear of the beach or to be placed in skips)
- Harvesting seaweed to be removed from the beach. Each stage must be described, including the following information:

- Equipment used, availability (equipment designed specifically to harvest seaweed (or not), in the case of repeated use, state potential periods when the equipment is unavailable), proximity (response time when requests are made)
- Human resources involved, roles and **if persons have safety equipment for** H_2S risks
- Combination of the three stages compared to each other
- Operating time for each type of equipment. For this last point, times must be recorded for the various machines used to complete a full operating sequence.

A clear description of these initial points is vital to subsequently identify options to optimise clean-up operation performance.

Remember to take plenty of photos to **illustrate your comments**.

1.3.2 Clean-up operation overview

The clean-up operation must also be evaluated as a whole (all stages together) to obtain clean-up operating data combined into a working day. To achieve this, the following information must be gathered.

1.3.2.1 Clean-up operation start time

The clean-up operation start time is the time when the team arrives on-site and not when they first start harvesting seaweed. The time to set up the equipment therefore counts.

1.3.2.2 Clean-up operation end time

The clean-up operation end time is the time when the last vehicle leaves the site and not when the last harvesting sweep was made. The time taken to remove all equipment from the site counts.

1.3.2.3 Clean-up operation running time

This is the period between the start and the end of the clean-up operation.

1.3.2.4 Operating time

The operating time is combined period of time that each machine is in operation, including harvesting seaweed in the water and/or on the beach, plus their transfer (to a trailer or to the top of the beach). The time taken to transfer the seaweed to a truck to remove them from the beach does not count.

1.3.2.5 Actual harvesting time

The actual harvesting time only refers to the periods when the harvesting machines are in action.

All the previously described technical data to be gathered are recorded in Table 2.

Table 2: Table summarising technical data **to be gathered on-site to organise the** clean-up operation

	Technique 1	Technique 2	…	Technique N
Clean-up operation start time (hh : mm : ss)				
Clean-up operation end time (hh : mm : ss)				
Clean-up operation running time (hh : mm : ss)				
Operating time (hh : mm : ss)				
Actual harvesting time (not incl. transfer) (hh : mm : ss)				
Actual harvesting time / period of clean-up operation (%)				
Actual harvesting time / operating time (%)				

2. Evaluation of harvesting technique yields

2.1 Gross yield (or specific)

Gross yield is calculated in relation to harvesting activities only. You should therefore time harvesting operations and compare it to the volume of seaweed collected.

For example, the gross yield for a mechanical digger is the volume of seaweed removed for one bucket load as illustrated in the following series of photos in Figure 6. If the bucket is 2.5 m^3 and one sweep of the bucket takes 1 minute to remove the seaweed and deposit it in a heap, the yield is 2.5 m^3per min^{-1}, i.e. 150 m^3per $hour^{-1}$.

Figure 6: Harvesting sequence using a long-reach excavator

For systems with a built-in seaweed storage capacity, the time taken to operate the harvesting system is proportional to the volume of seaweed collected in the integrated storage bins or hoppers.

For manual collection operations, the quantity of seaweed manually transported and stored in heaps is proportional to the time take by clean-up operators to harvest the seaweed and the number of people present.

2.2 Integrated (combined) yield

Integrated yield accounts for seaweed transfer operations plus site set-up/exit time for all equipment and staff. Returning to the example of the long-reach excavator shown in Figure 6, we assume that the excavator arrives on-site at 8 am and leaves at 12 pm. In terms of gross yield, by taking a maximum volume of 600 m3 that could be harvested, counting the time to manoeuvre the excavator and staff rest-breaks, the assumption results in a final volume of 400 m^3 calculated once the clean-up operation has ended. The integrated yield is therefore 100 m^3 per $hour^{-1}$.

3. Harvesting technique efficiency

Measuring the efficiency of a harvesting technique compares the percentage of seaweed gathered during one clean-up operation to the initial biomass present on-site. The figure is indicated, in particular, for mechanised harvesting operations on beaches. Harvesting efficiency in water is more difficult to calculate as the motion of water quickly reforms floating seaweed into mats.

For example, the efficiency of a surf rake, illustrated in Figure 7, can be measured by calculating the algal biomass before and after using the surf rake. The subsequent result both indicates the proportion of seaweed harvested compared to the total amount present at the start and calculates the number of sweeps made by the surf rake to remove most of the seaweed. If we assume that initial biomass contained in a 0.25 m² quadrant is 5 kg and the remaining biomass after using the surf rake is 2.5 kg (still in the 0.25 m² quadrant), it is likely that a second sweep in the same place will remove virtually all the biomass present. Make sure you check that the reduced depth of the beached seaweed after the first sweep of the surf rake does not radically alter harvesting capacity. This type of equipment must be tested on different thicknesses of beached seaweed.

Figure 7: Image of a surf rake being used to harvest sargassum seaweed

4. Harvesting technique selectivity

Selectivity in harvesting techniques focuses on their capacity to collect seaweed strandings by removing as few additional materials as possible (water, sand). Gathering these data is key for guidance about subsequent means of recovering and recycling seaweed. In addition, sand content readings can also help assess possible effects of harvesting on beach erosion.

4.1 Taking samples

Seaweed samples must be taken at several points in the harvesting process:

- immediately after harvesting, ideally taken directly from the harvesting machine (bucket, net, end of conveyor belt, etc.)
- before being removed from the beach (in a skip or a pile after draining)

Seaweed samples must be taken using a measuring bucket (generally 10l). The sampling procedure must completed taking into account just how compressed the seaweed is on ground. Ideally, a minimum of three samples must be taken to assess the variability of the results obtained. When seaweed samples are taken after draining, especially from piles of seaweed left at the top of the beach, samples must be taken from different heights (top, middle, bottom), as water and sand content can be higher at the foot of the pile.

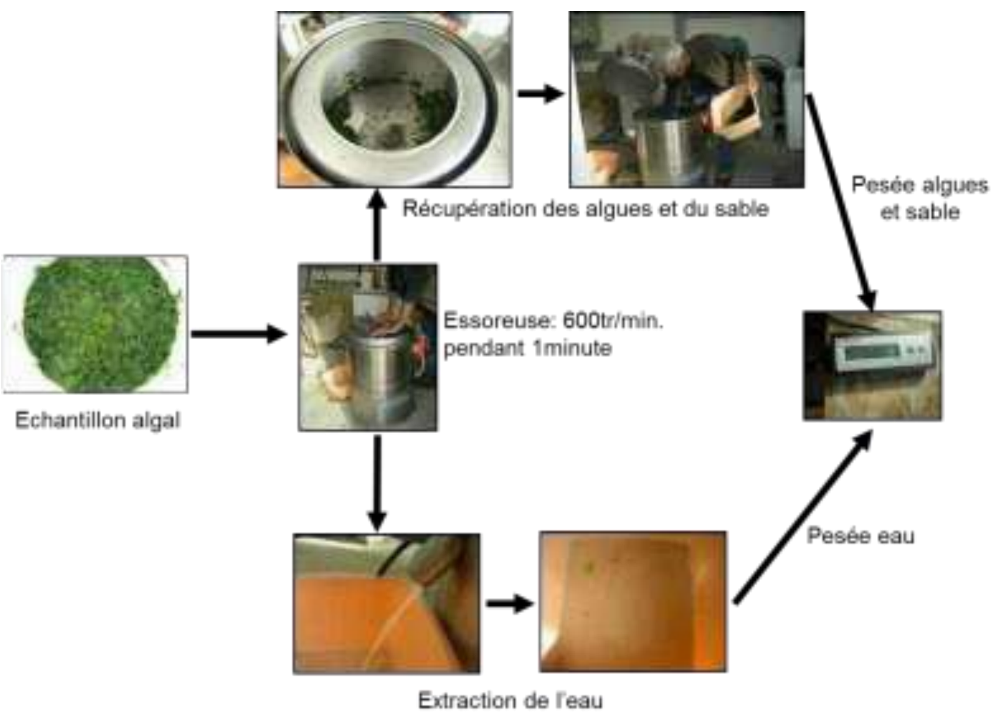
4.2 Water content in harvested seaweed

4.2.1 Extracellular water content

Depending on the technique used, once the harvesting has been completed, the pile of seaweed collected can contain a large amount of water. This water is solely extracellular water, i.e. water that can be removed by spinning or pressing the seaweed. These data can be evaluated directly or indirectly.

- Direct evaluation (recommended for samples gathered in water and low in sand)

The unwashed sample collected on-site (in a measuring bucket) is weighed prior to any analysis. It is then placed in an industrial centrifuge to spin the seaweed in a uniform manner. The spin speed is set at 600 rpm for the sand to be separated from the seaweed during the spin cycle. Water exits through a discharge pipe placed at the bottom of the centrifuge and is then weighed. The spun seaweed mixed with sand is also collected and weighed. The whole procedure is illustrated in Figure 8. The seaweed sample is then rinsed to assess its sand content, as described in section 4.3.



Récupération des algues et du sable	Collecting seaweed and sand
Pesée algues et sable	Weighing seaweed and sand
Echantillon algal	Seaweed sample
Essoreuse : 600 tr/min. pendant 1 minute	Centrifuge: 600 rpm. for 1 minute
Pesée eau	Weighing the water
Extraction de l'eau	Removing water
Récupération des algues et du sable	Collecting seaweed and sand
Pesée algues et sable	Weighing seaweed and sand

Figure 8: Description of the procedure **to directly assess** extracellular water content in harvested seaweed

- Indirect evaluation (recommended for samples contained large amounts of sand)

As industrial centrifuges are hard to come by, an indirect analytical method for samples can be used to identify the extracellular water content in samples. The first step in the sampling process is always the same (place the sample in a measuring bucket and weigh it before rinsing). The sample is then rinsed and its sand content assessed as described in section 4.3. The seaweed is then weighed to find the fresh weight after draining for 1 minute then spun using a hand-operated centrifuge (salad spinner) until no more water is removed. The spun seaweed is then weighed a second time

4.2.2 Intracellular water content

Conversion factors must be defined to switch from fresh weight after draining for 1 minute (the easiest method to use on-site) to fresh spun weight and dry weight. These conversion factors provide a common benchmark regardless of the type of algal matter analysed.

Dry weight is defined by the weight after an appropriate drying operation. Ulva seaweed is dried in an oven at 60°C for 48 hours. If no oven is available, the weather in the French West Indies means that seaweed can be dried naturally in the sun. The dry weight of the seaweed must be checked on an hourly basis until the reading stabilises. This results in the dry weight reading.

4.3 Harvested seaweed sand content

The seaweed sample is rinsed in running water. If the sample is visibly loaded with sand, it can be rinsed several times. The seaweed is then carefully and gradually removed from the rinsing basin. Water is then removed from the sample as much as possible (step 1, Figure 9).

The measuring bucket used to collect samples is then rinsed to collect the sand in an appropriately sized container. The overlying water is then removed and a fresh weight reading can be given for the sand. The sand is then dried (in an oven or in the sun) to measure it's dry weight (step 2, Figure 9).

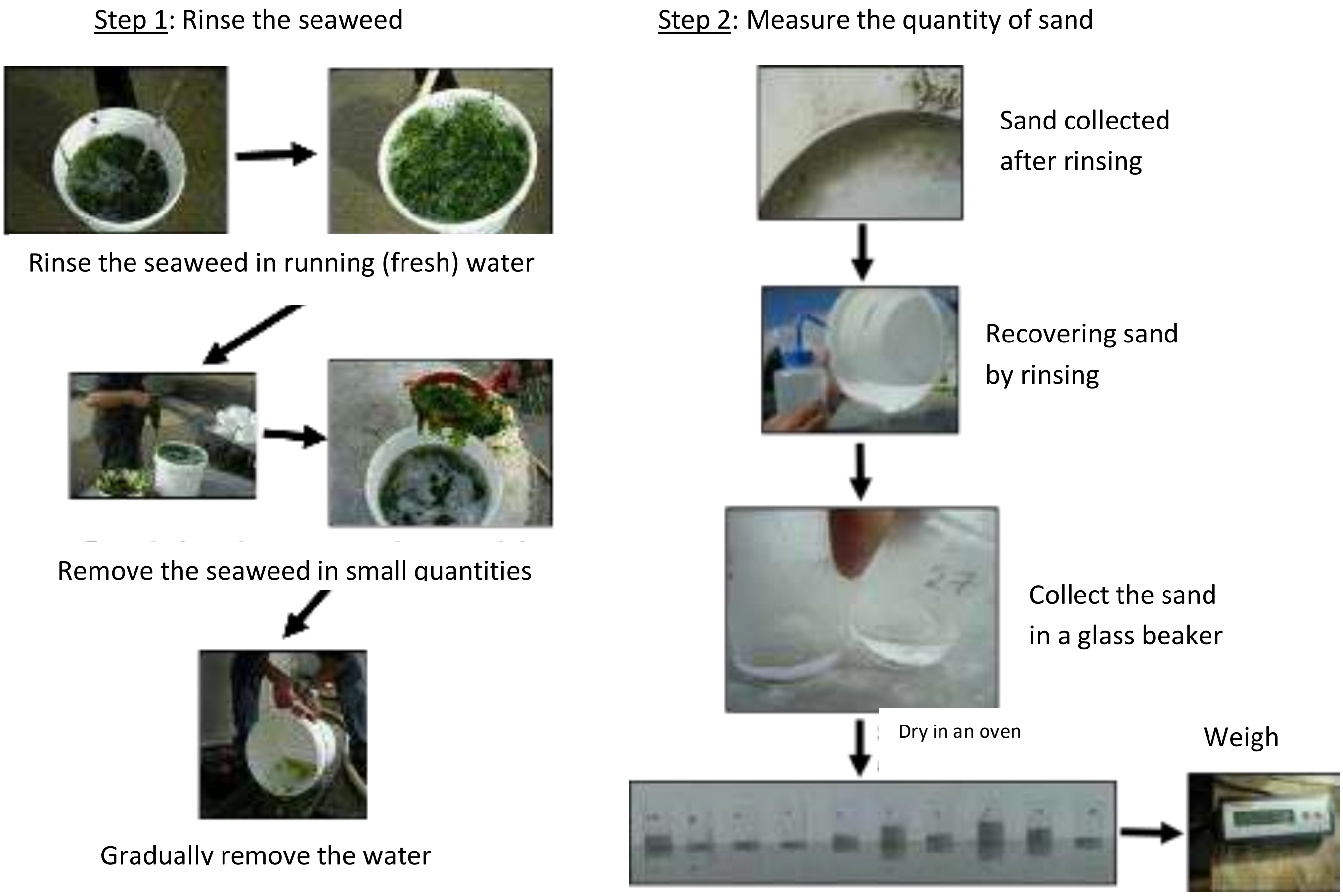


Figure 9: **Description of the procedure to** determine the sand content of harvested seaweed

5. Environmental impacts

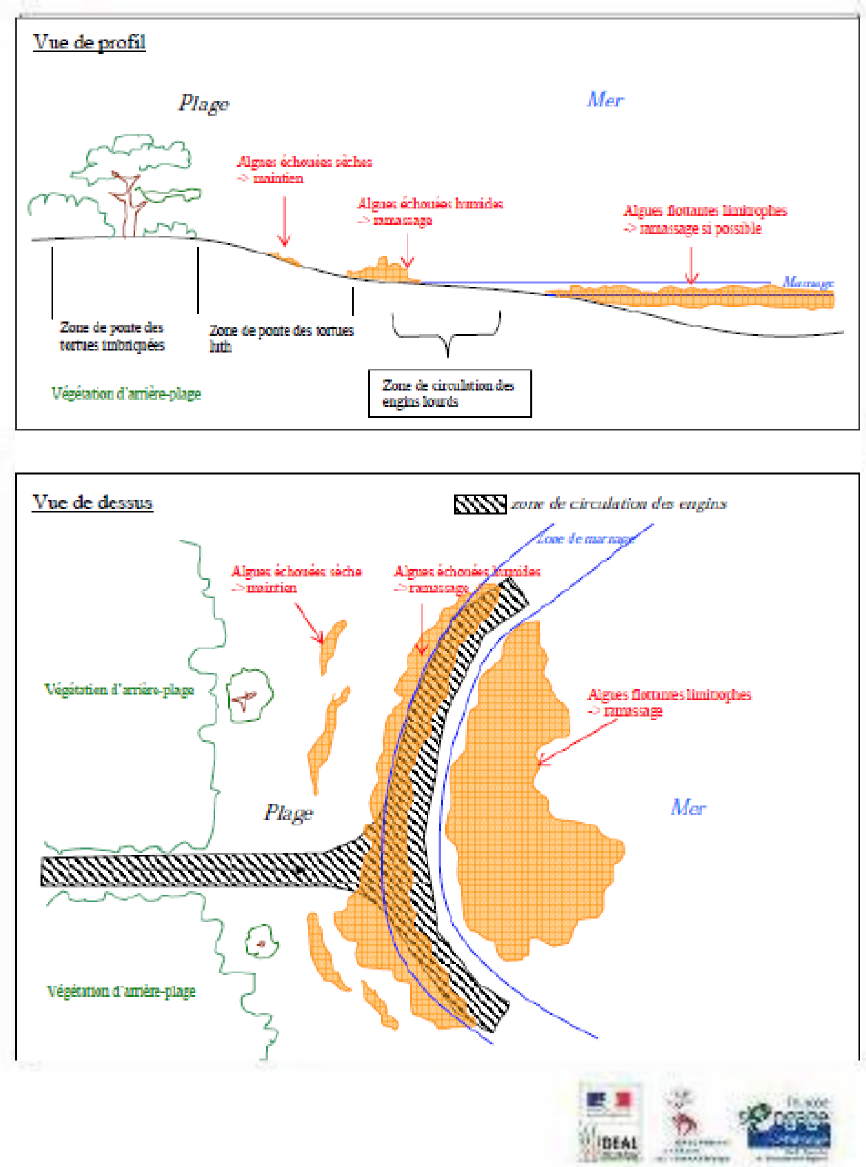
5.1 Clean-up site access

When there is no dedicated access to a clean-up site such as a slipway or wide, unmetalled tracks commonly used to access a site, manoeuvring heavy machinery in areas not designed for their use can cause damage to flora when creating an access route (clearing undergrowth, cutting down trees, etc.) and by subsequently using the track. The size of the area affected must be estimated and the plant species concerned identified. Sites with major environmental challenges should be studied to identify the location for an access route with the least impact.

5.2 On the clean-up site

Collecting seaweed can have several effects on fauna, particularly crushing and accidental trapping of species.

Animals can be crushed as heavy machinery moves around on beaches. In Martinique, sea turtle nests are sometimes prone to this risk. As a reminder, the sea turtle nesting season is from April to October. To avoid damaging sea turtle nests as much as possible, the REFLEXE guidance note on "Environmental measures for mass seaweed strandings on the coast of Martinique" recommends manual clean-ups first and foremost. When mechanised collection methods are required, harvesting operations are best done at low tide when the machinery can access the lower parts of the foreshore directly and perpendicularly to the beach. The same route can be taken when exiting the beach. All these recommendations are shown in Figure 10.



Plage	*Beach*
Mer	*Sea*
Algues échouées sèches -> maintien	Dry, beached seaweed -> leave
Algues échouées humides -> ramassage	Wet, beached seaweed -> collect
Algues flottantes limitrophes -> ramassage si possible	Floating seaweed adjacent to the shore -> collect if possible
Marrage	*Tidal zone*
Zone de ponte des tortues imbriquées	Hawksbill sea turtle nesting area
Zone de ponte des tortues luth	Leatherback sea turtle nesting area
Végétation d'arrière-plage	Backshore vegetation
Zone de circulation des engins lourds	Heavy machinery turning area
Vue de dessus	Plan view
zone de circulation des engins	*heavy machinery turning area*
Algues échouées sèches -> maintien	Dry, beached seaweed -> leave
Algues échouées humides -> ramassage	Wet, beached seaweed -> collect
Végétation d'arrière-plage	Backshore vegetation
Algues flottantes limitrophes -> ramassage	Floating seaweed adjacent to the shore -> collect
Plage	*Beach*
Mer	*Sea*

Figure 10: Illustration of good harvesting practice in sensitive areas linked to sea turtle nests (diagram taken from the REFLEXE guidance note).

In addition, an impact assessment for driving over sea turtle nests could be undertaken by recreating a nest to test out with a vehicle. The artificial nest should be positioned at the average depth where turtles bury their eggs together with the right amount of sand heaped up to cover the eggs. False eggs can be made to the same size as real ones with similar tolerance levels. Using real egg shells after hatching is also possible.

When the eggs hatch, the young turtles can be found in piles of seaweed washed up or floating near the beach. As a result, they can be accidentally trapped when collecting seaweed either on the beach or in the water. Broadly speaking, shoreline fauna can be unwittingly removed when collecting seaweed. During collection trials, several volumes of harvested seaweed (minimum 1 m^3) should be visually checked to count how many animals have been accidentally removed. Any animals that may have been dead before harvesting should not be counted. At the same time, rubbish can also be recorded as some strandings can contain large amounts of waste, as shown in Figure 11.

Figure 11: Image of refuse items contained in seaweed strandings.

If heavy machinery is used to harvest seaweed, animals may also be crushed by their movements. A small, hand-held net dragged behind the harvesting vehicle can pick up any animals that have been crushed.

Harvesting operations can also cause beach erosion and subsidence directly from the vehicles moving about on the beach and by removing sand when they collect seaweed. The formation of piles of seaweed can result in indirect erosion by causing the movement of water to hollow away the beach at high tide.

Figure 12**: Image of a beach being eroded by large piles of seaweed** that change **water movement patterns at high tide.**

5.3 Drainage site

Seaweed should not be stored even on the ground or in the open air except if it is totally dry. Indeed, if freshly collected seaweed is deposited on the ground it can cause soil disturbance from substances that may leach into the ground with water draining from the seaweed and fermentation fluid (salts, chemical substances, etc.). Furthermore, wet and non-aerated piles of seaweed can generate H_2S which poses a risk to neighbouring communities.

In theory, seaweed should be removed for treatment no later than 48 hours after collection. Generally, seaweed is left on the beach to drain water for the first 24 hours, which removes most of the seawater and reduces the volume of the seaweed to be transported. Also, this is the period when the most appropriate solution to remove the seaweed is identified.

Drainage areas can be identified elsewhere onshore if the beaches are too small for this stage in the process. These drainage areas are gently sloping coated paved areas that channel water to a leak-proof storage pond. The piles are left uncovered for natural aeration while the walls stop spreading. Seaweed should be stored in piles no more than 1-metre high. The size of these storage areas should match the volumes harvested on a daily basis.

Once the seaweed has been removed from the beach or drainage areas (no more than 48 hours after harvesting), it must be taken for treatment where it will be stabilised then processed.

The current situation in Martinique means that not all of these recommendations can be followed. Existing treatment processes cannot always cope with the volumes collected. Longer-term storage sites should be identified until the excess material can be treated. The weather in the French West Indies is ideally suited to natural drying. For example, facilities such as drainage sites can be identified by assessing times needed to completely dry out seaweed and the right thickness for rapid drying at all depths to prevent any risk of fermentation.

Once dry, the resulting biomass can be processed, via shredding to reduce its volume and then be added to products for agricultural use. This process requires additional research to ensure that natural drying does not release H_2S, in which case, sealed facilities should be provided. A study on the chemical composition of shredded seaweed would also be needed to allow for its use in agronomic processes.

6. The outcome of seaweed removed from the harvesting site

When seaweed collection trials allow, the outcome of the harvested material should be described by specifying:

- transportation conditions
- the destination and what the seaweed will be used for (composting, spreading on farmland, storage, other)
- the distance travelled and travel time
- time taken between being stored on the beach and removal

7. Community impacts

7.1 Harvesting seaweed and employment

Harvesting seaweed can generate jobs. The main difficulty for this sector is that the jobs are mostly insecure as strandings are variable. Clean-up companies must be asked about harvesting activities to ascertain if they are likely to generate jobs and for what kind of activity, stating the related arduous nature of the work and risks.

Green brigades or shoreline guardians can be developed in the longer-term to monitor the coast and issue warnings when rafts of seaweed drift near to the shore or wash up on the beach. They can also work on other environmental tasks the rest of the time. Green brigades can also be involved in communication campaigns and monitor the coastal areas, areas that require further development.

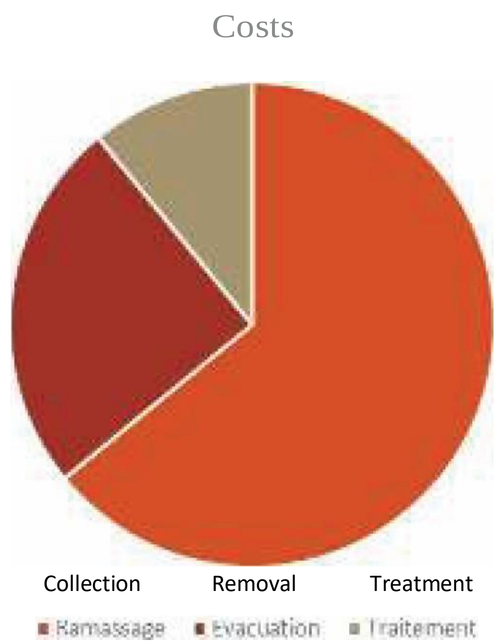
7.2 Harvesting and population

Beach clean-ups are noisy and can also cause H_2S to be released, thereby creating foul smells and the significant health and safety risks for neighbouring communities. Prior to beginning any clean-up operation, the surrounding community must be informed about the planned activities. If the wind is blowing towards homes and the beached seaweed is rotting or may give off H_2S when handled, operators should either postpone the clean-up operation as a matter of safety or ask residents to leave their homes while the seaweed is collected. For clean-up operations with health risks, atmospheric H_2S concentrations must be constantly monitored on-site and around local homes. Once the clean-up operations have been completed, it would be good to ask the local community about any nuisance experienced when collecting the seaweed and how they felt the clean-up operations were conducted.

More generally, on-site visits have shown that local communities are interested in seaweed strandings. Some scan the seas every morning while others experience discomfort such as burning eyes.

Given local community interest, a participatory project could be envisaged with the form and content to be decided on. Fishermen can also report their observations when returning to port. In the absence of specific reports, these contributions would help identify if seaweed was present in large quantities or not.

Economic assessment of a seaweed clean-up operation



Calculating clean-up costs would help develop a better financial strategy to be adopted, be it for purchasing or leasing equipment or the various options for possible recovery and recycling.

1. On-site clean-up costs

Although clean-up operations are entirely outsourced, the company tasked with collecting the seaweed will provide their hourly or daily rate.

If a harvesting vehicle has been purchased, the following aspects can be assembled to calculate the overall cost for the clean-up operation:

- Human resources required for the anticipated clean-up technique
- Personal protective equipment (H_2S detector, personal respirator mask)
- Safety equipment maintenance (spare cartridges, gas detector calibration, etc.)
- Purchase cost of harvesting vehicle
- Vehicle servicing costs (checks, specific spare parts, cleaning)
- Human resources needed to maintain the vehicle
- Fuel costs
- Depreciation costs

The cost is calculated based on recorded yields during trials and targets to be achieved to reach the required operating period.

2. Seaweed removal costs

Seaweed removal costs can be calculated from hourly/daily rates provided by the contractor tasked with the clean-up.

The daily rate will be equivalent to the potential volume of seaweed to be removed calculated from recorded yields from trials (taking into account loading times and the number of tipper trucks available for removal). This calculation also accounts for the number of skips used per day based on the envisaged clean-up solutions for the seaweed once it has left the beach.

3. Seaweed treatment costs

If an existing company is treating the seaweed, the business managers will disclose the cost directly. By contrast, if the intention is to build storage or composting platforms, the construction, H_2S risk compliance, maintenance and commissioning costs for these facilities must be calculated.

Cross-method evaluation matrix

	Rendement	Efficacité (P = 2)	Sélectivité (P = 2)	Disponibilité	Accessibilité (P = 3)	Impact (P = 4)	Score
Technique 1	4	6	2	3	6	4	25
Technique 2	3	4	6	2	12	8	35
Technique 3	2	2	8	4	9	12	37
Technique 4	1	8	4	1	3	16	33

Coûts	Costs
Ramassage	Collection
Evacuation	Removal
Traitement	Treatment

Several methods can be used to objectively compare the various harvesting techniques attempted. One evaluation method was selected for description to attribute a final score to each harvesting method.

1. Devising the matrix

The matrix has been designed so that the harvesting techniques are in row headings with the evaluation criteria in column headings.

1.1 Choice of discriminatory criteria

The discriminatory criteria are devised for the intended purpose. For sargassum collections, the aim is to identify the most appropriate technique for the stranding pattern, the site constraints and the intended seaweed removal target. As a result, the following criteria are proposed:

- Yield
- Efficiency
- Selectivity
- Availability
- Accessibility
- Impact

Each technique is then ranked against each criterion from 1 to n (number of techniques to be ranked). For example, if 4 techniques must be compared, a score of 1 to 4 will be given to each based on their performance. Table 3 provides an example.

Table 3**: Assigning a score from 1 to 4 for** each technique and each criterion selected, with **1 corresponding to the score for the lowest yield, efficiency, selectivity, availability and accessibility and 4 for the highest.**

	Rendement	Efficacité	Sélectivité	Disponibilité	Accessibilité	Impact	Score
Technique 1	4	3	1	3	2	1	14
Technique 2	3	2	3	2	4	2	16
Technique 3	2	1	4	4	3	3	17
Technique 4	1	4	2	1	1	4	13

Coûts	Costs
Ramassage	Collection
Evacuation	Removal
Traitement	Treatment

1.2 Choice of discriminatory criteria

According to site and specific characteristics, some criteria can subsequently be weighted to promote them in relation to others. For example, on highly environmentally sensitive sites, accessibility, efficiency and selectivity impacts can be weighted to have greater influence. Table 4 shows the results obtained from weighting these criteria on the basis that the weighting between the selected criteria can be identical or different.

Table 4: Results obtained by weighting certain criteria.

	Rendement	Efficacité (P = 2)	Sélectivité (P = 2)	Disponibilité	Accessibilité (P = 3)	Impact (P = 4)	Score
Technique 1	4	6	2	3	6	4	25
Technique 2	3	4	6	2	12	8	35
Technique 3	2	2	8	4	9	12	37
Technique 4	1	8	4	1	3	16	33

Taking the example given, technique 3 would be the most appropriate. That said, as there is very little difference with technique 2, it would be useful to review both techniques prior to making a final decision

Coûts	Costs
Ramassage	Collection
Evacuation	Removal
Traitement	Treatment

APPENDICES

Appendix 1: E*quipment required to gather data on-site*

Appendix 2*: Creating a conversion table*

Appendix 3*: Reminder of the type of sample to take on-site and sample processing procedure*

Appendix 4*: Evaluation matrix*

Appendix 5*: Simplified evaluation matrix*

Appendix 1: Equipment required to gather data on-site

Safety equipment

H_2S detector, filter cartridge gas mask

Description of site materials:

Map and/or aerial photograph of clean-up site, items for taking notes (waterproof paper and pencil, ideally), digital camera (waterproof, if possible), GPS device (waterproof, if possible)

On-site measuring equipment:

Net with a known aperture width, standard sampling "potato" sack, scales, quadrant (ideally, stainless steel), closable measuring bucket (x10), stopwatch, metre rule, tape measure (ideally stainless steel) to measure skips. Small "freezer bag" sample bags and a marker pen are useful.

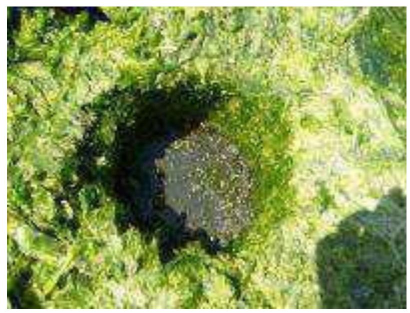
APPENDIX 2: Creating a conversion table

A conversion table can be created to facilitate and reduce on-site measurements, to convert readings for the thickness of drained seaweed after 1 minute to spun weight and dry weight.

This involves measuring the biomass of several (fresh) seaweed strandings of different thicknesses to find the relationship between these two parameters. The biomass will then be measured by drained weight after 1 minute, spun weight and dry weight.

The methodology applied can be based on that developed by CEVA for ulva seaweed, featured below:



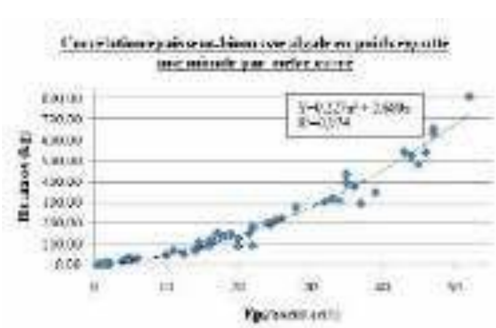


The thickness of the seaweed strandings is measured on-site. and a sample taken using a stainless steel coated cylinder with a known size pressed into the seaweed. The seaweed samples are taken manually in the cylinder. A craft knife or other bladed instrument may be required to slice the seaweed.



Once in the laboratory, the sample is rinsed and weighed after being left to drain for 1 minute.


Next, the sample is placed in a centrifuge to obtain its spun weight. The sample can then be dried in the oven to obtain its dry weight.



The results obtained for several dozen samples can establish the various conversion factors required.

APPENDIX 3: Reminder of the type of sample to be taken on-site and sample processing measures

✓ Evaluating the total stock of seaweed present on-site


Quadrants

taking seaweed samples

drained weight 1 minute

✓ Calculate the biomass of newly harvested seaweed on leaving the clean-up site (after drying)

Take a sample of seaweed of a known volume

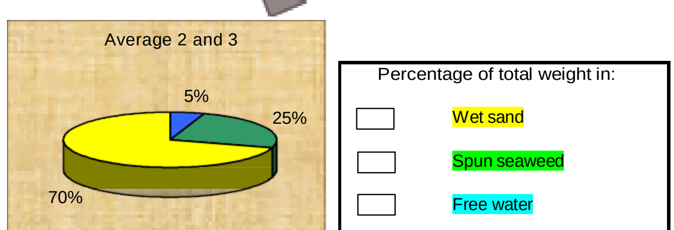
Weigh the unwashed sample

Wash the sample

Sand	Seaweed
Wet weight	Drained weight after 1 minute
Dry weight	Spun weight
	Dry weight

Identify the composition of strandings

	Average deposits
Average amount collected	753
Seaweed drained after 1 min (kg/m3)	455
Spun seaweed (kg/m3)	185
% (spun/drained after 1min)	41%
Dried seaweed (kg/m3)	38
% (dry/spun matter)	20%
Wet sand (kg/m3)	528
Dry sand (kg/m3)	317
% (Dry/wet sand)	60%
'free' water	40



APPENDIX 4: Assessment form

Sargassum clean-up operation checklist

Operator (full name): ………………………………………………………………………...
Date: / /

1. Clean-up operation context

Clean-up site - municipality: ……………………………………………………………
Site name and description:
……………………………………………………………………………………………
…………………………………………………………………………………………......

- ☐ beach
- ☐ port
- ☐ bay head
- ☐ rip-rap
- ☐ mangrove
- ☐ other:

Description of accessibility:
....
....

Appearance of seaweed to be collected (state if fresh, old or mixed)
☐ consistent, thin layer of seaweed (estimated thickness: ………)
☐ consistent, thick layer of seaweed (estimated thickness: ………)
☐ scattered seaweed
☐ beached seaweed (state if seaweed forms a mat or bank and specify average thickness)
☐ seaweed with a 'crust' (state if the seaweed is mostly floating in water or in the inter-tidal zone and if there are any visual signs of rotting (white blotches, fluid, etc.)

Estimation of the quantity of seaweed present (show your calculation and number of samples measured and their locations):
....
....

Attach an annotated map of the site featuring the position of the seaweed strandings, locations of samples taken to measure biomass and access. Add photos required.

Estimation of the date of the seaweed stranding or when the seaweed was observed on the site (in days):
....
....

Weather conditions (please include wind direction):
....

Health and safety conditions (reading of H_2S point concentrations Is seaweed decaying?)
....
....
....

Administrative status of clean-up operation (supported by ADEME? By another funder? Requested by a municipality?):
....
....

Institutions present in addition to the private company (DEAL, Town council, Madininair, other):
....
....
....

Prior agreements or authorisations obtained:
....
....
....

2. Description of the method used

- ☐ manual onshore collection
- ☐ mechanised onshore collection
- ☐ offshore collection

Equipment used (State the model and vehicle manufacturer for seaweed harvesting machinery – attach technical specifications, if possible)

➔ Please take plenty of photos.

For seaweed collection:
....
....
....
....
....
....
To transport seaweed:
....
....

Please fill in the table below:

	Technique 1	Technique 2	...	Technique N
Harvesting method				
Harvesting area				
Harvesting tool				
Location of the harvesting tool				
Dimensions				
Working depth/ thickness				
Additional equipment/tools				
Seaweed storage				
Seaweed transfer				
Power (HP)				
Fuel consumption (L/h^{-1})				
Speed (when not harvesting)				
Speed (when harvesting)				

Labour requirements

Total number of people required to carry out the clean-up operation:

....

For supervision:

....

To drive/operate machinery:

....

To transport seaweed:

....

Other (manual collection, technical support, etc.) - please describe:

....

....

....

....

Specify the nature of labour (company employees? Temporary workers recruited for the clean-up operation (fishermen, etc.):

....

....

Seaweed collection organisation/phases - please describe:

....

....

....

....

....
....
....
....
....
....
....
....

Has the harvesting technique already been used? Where? With what level of success?
....
....
....
....
....
....
....

Contractor:
....
Commissioned by
....

3. Technical performance

Objectives:

- Performance assessment: volume and weight of wet seaweed collected
- Describe the seaweed collected: cleanliness, quantities of sand
- Clarify the effect of the clean-up arrangements (rotations between processing/storage facilities, clean-up operation preparation time, etc.) on harvesting operations
- State the precautions taken and errors to avoid when maintaining equipment or running the clean-up operation, etc.

➔ Please take plenty of photos.

Estimation of percentage of sand:
....

Description of foreign objects collected (rubbish, etc.):
....

Volume collected (estimate from the tipper truck capacity, measure the height and width of the skip if needed – show your calculations):
....
....
....
....
Tonnage collected (specify the collection method: weight data slip? Estimation? Calculation details):
....

Clean-up operation running time:
………

Comments on volume collected:
………
………
………
………

Measures taken for health and safety:
………
………

Advantages of the method:
………
………
………

Problems encountered:
………
………
………

Opportunities for improvements:
………
………
………

Please fill in the table below:

	Technique 1	Technique 2	…	Technique N
Clean-up operation start time (hh : mm : ss)				
Clean-up operation end time (hh : mm : ss)				
Clean-up operation end time (hh : mm : ss)				
Operating time (hh : mm : ss)				
Actual harvesting time (not incl. transfer) (hh : mm : ss)				
Actual harvesting time / period of clean-up operation (%)				
Actual harvesting time / period of clean-up time (%)				

4. Seaweed transfer and recycling/recovery

Objectives:

- Evaluate logistical arrangements to transfer the seaweed based on collection methods (equipment used, number of rotations, etc.)
- Evaluate the suitability between the seaweed harvesting technique and the reception criteria for seaweed to be recycled or re-used

Has the seaweed been taken away after being collected? How (skips, trucks, etc.)? By who?

....
....
....
....

Is the number of rotations enough?

....
....

What is the volume of seaweed transported in each rotation?

....

What is the weight per rotation (estimate using a sample of a known volume - state how many samples were taken and the conditions when taking the samples)?

....

Does the transportation method hinder collection yields?

....
....
....
....

Is the transportation equipment appropriate for the task (specific anticorrosion treatment)?

....
....
....
....

Destination of transported seaweed:

% of collected seaweed sent to a composting plant: ….. %
Which plant:

....
....

If rejected by the treatment facility, please state why and what amount:

....
....

% of collected seaweed given to farmers: ….. %
How?
Describe
....
....

% of collected seaweed stored and not recycled/reused: …%
Where?
…………………………………………………………………

5. Environmental impact

The purpose is to assess the consequences associated with each harvesting technique. The indicators will be mostly qualitative.

Describe the effect of the harvesting technique on the natural environment (when accessing the clean-up site and collecting seaweed): (Beach subsidence? Erosion? Impacts on fish? Impacts on biocenoses (biological habitats or communities)? Risk of crushing sea turtle nests?)
....
....
....
....
....
....
....
....
....
Describe actions to limit effects (beach movement procedures, altering the collection process during the clean-up operation, etc.)
....
....
....
....
....
....
....
....

6. Other

Local residents' views about the clean-up operation:
....
....
....
If farmers come to collect seaweed, are they informed about precautions to take (20 t/ha max., drained seaweed advised, etc.)?

....

7. <u>Economic data (if data can be gathered)</u>

<u>Objectives</u>

- Evaluate the economic benefits of each harvesting technique for various strandings patterns
- Estimate the additional costs and savings to be made

If the municipality undertakes the clean-up: cost of daily clean-up operation (daily rate):

....

Does this include transport? ☐ yes ☐ no

Estimate the costs for the contractor to undertake the clean-up operation (daily rate):

....

Wages:

....

Fuel:

....

Equipment hire:

....

Equipment depreciation:

....

Consumables:

....

Others:

....

% of costs associated with transport:

Opportunities to cut costs:

....

....

....

....

....

....

....

APPENDIX 5: Simplified assessment form

Daily "pilot sargassum clean-up operation" monitoring form

Company:
....

Date: /   /

Clean-up operation start time: ……………………. End time: …………………………..

Quantity of seaweed collected, in tonnes, based on CVO weighing slips or other composting platforms. If estimated. Please include your calculations and units (t, m^3):

....

....

Quantity of seaweed removed, in tonnes. Please include your calculations and units (t, m^3):

....

....

Estimate the % of sand: ……………………………………………………………………………………………………

Clean-up site / municipality: ………………………………………………………………………………………..

- ☐ beach
- ☐ port
- ☐ bay head
- ☐ rip-rap
- ☐ mangrove
- ☐ other:

Description of accessibility:

....

....

Description of seaweed to be collected

- ☐ consistent, thin layer of seaweed
- ☐ consistent, thick layer of seaweed
- ☐ scattered seaweed
- ☐ beached seaweed
- ☐ other (describe)

Is the seaweed fresh or rotting? ……………………………………………………………….

....

Estimation of the date of the seaweed stranding or when the seaweed was observed on the site (in days):

....

<u>Description of the method used</u>

Equipment used for collecting the seaweed (specify for the 1st rotation then state any changes made thereafter):

....

....

....

For transport (number of skips, trucks. State the truck load capacity):

....

....

....

....

Labour requirements

Total number of people present at the clean-up site:...

For supervision: ....

To drive/operate machinery:...

For transport: ....

Other (manual collection, technical support, etc.) - please describe:

....

....

Seaweed collection organisation/phases - please describe (specify for the 1st rotation then state any changes made thereafter):

....

....

....

....

....

Measures taken for health and safety:

....

....

Key strengths of the harvesting method:

....

....

....

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....

Difficulties encountered:

……

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……

……

……

Opportunities for improvements:

……

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……

……

<u>Destination of removed seaweed:</u>

☐ Composting (state which platform)
☐ Storage (state which site)
☐ The seaweed was not removed
☐ Other (please describe):

If the seaweed was rejected by a treatment facility, please state why and give the amount:

……

APPENDIX 3 "ASSESSMENT FORM FOR EXPERIMENTS TO HARVEST SEAWEED"

"Pilot sargassum clean-up operation" assessment form

General information

Date: / /

Company:

....

Type of equipment used:

- ☐ Mechanised onshore collection: …………………….
- ☐ Mechanised offshore collection: ……………………
- ☐ Manual collection: ……………………………….

Arrival time at the clean-up site: ……………….. Departure time: ………......................

....

Clean-up operation start time: …………………End time: ………...............................

....

Clean-up operation start date: ………………………End date: ………………….

....

Clean-up operation administrative status (ADEME? Other funder?):

....

Institutions present (town council, DEAL, ADEME, etc.):

....

Clean-up operation supervised by (full name):

....

Site description

Location (municipality/site):

....

....

- ☐ beach
- ☐ port
- ☐ bay head
- ☐ rip-rap
- ☐ mangrove
- ☐ other:

Description of accessibility:

....

....

....

Ease of heavy machinery movements:

....

....

Weather conditions:

....

Specific challenges:

- Local residents? :

  ....

- Bathers, tourists?

  ....

- Sea turtle nesting site?

  ....

- Site for play, sporting or educational activities?

  ....

Description of seaweed stranding

Type of stranding

- ☐ consistent, thin layer of seaweed: …………………………………………………
- ☐ consistent, thick layer of seaweed: ……………………………………………………
- ☐ scattered seaweed
- ☐ beached seaweed
- ☐ other (describe)

....

....

Is the seaweed fresh or rotting?

....

....

Estimation of the date of the seaweed stranding or when the seaweed was observed on the site (in days):

....

....

Drained weight after 1 minute for 1/4m²):

- Average thickness (m):

  ....

- Weight (kg):

  ....

- Estimated weight per m²:

  ....

- Estimated weight per m^3 ((weight x 4)/thickness)):

  ....

Estimated level of coverage (%):

....

Estimated surface area of stranding (GIS, on-site measurements in m²):

....

....

Estimated average thickness (m):

....

Total estimated volume (Surface area*thickness*coverage, in m^3):

....

Estimated total mass: (estimated volume *drained weight $_{\text{after 1 min}}$, in kg):

....

Seaweed samples (10 l):

- Number

  ....

- Description:

  ....

  ....

....

....

....

....

....

....

....

....

In the laboratory (for a volume of 10 L):

	1	2	3	4	5
Weight of seaweed without sand ('fresh', drained)					
Mass in m^3					
Weight of seaweed without sand (dry)					
% of initial mass					
Weight of dry sand (for 10 L)					
Mass of sand for $1m^3$					
% of sand for 1 tonne* of wet seaweed					

*$1m^3$ of seaweed = ………tonne

Comments:

....

....

....

....

....

....

Description of seaweed harvesting method

Equipment used

For collecting the seaweed (specify for the 1st rotation then state any changes made thereafter):

....

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....

For transport (number of skips, trucks. State the truck load capacity):

....

....

....

....

....

....

Total number of people present at the clean-up site:

....

For supervision:

- For trials

  ....

- Finally

  ....

To drive/operate machinery:

....

- For trials

  ....

- Finally

  ....

To transport seaweed:

....

- For trials

  ....

- Finally

  ....

Other (manual collection, technical support, etc.) - please describe:

....

....

....

....

Seaweed collection organisation/phases - description of a cycle:

....

....

....

....

....

....

....

Quantity of seaweed collected in tonnes per m^3, based on CVO weighing slips or other composting platforms. If estimated. Please include your calculations and units (t, m^3)

- For one cycle:

....

....

- In the day:

....

....

Quantity of seaweed removed, in tonnes per m^3. Please include your calculations and units (t, m^3):

....
....

....

<u>Destination of removed seaweed:</u>

- ☐ Composting (state which site) ………………………………………………….. - .... %/m^3/t
- ☐ Storage (state which site)……………………………………………….. - ....%/m^3/t
- ☐ The seaweed was not removed……………………………………………….. -……....….%/m^3/t
- ☐ Other (please describe): ……………………………………………….. - .... %/m^3/t

....
....

If the seaweed was rejected by a treatment facility, please state why and give the amount:
....
....
....

Measures taken for health and safety:

....

....

....

....

Effect of the method on the surrounding environment:

....

....

....

....

....

....

SUMMARY

Key strengths of the harvesting method:

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....

Difficulties encountered:

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Opportunities for improvements:

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....

APPENDIX 4
"FACTSHEETS"

EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – BEACH GROOMER

GENERAL DATA

Field: Mechanised onshore seaweed collection
Equipment: Beach groomer
Company: SEEN

EQUIPMENT

The beach groomer is a towed piece of machinery and has teeth mounted on springs to comb the beach surface to gather objects lying on it.

Towed beach groomer

The main features are show below (manufacturer's data):

- ✓ **Pulling power**: 4x4 agricultural tractor (80 cv minimum);
- ✓ **Tyres**: low-pressure high load-bearing;
- ✓ **Length**: 2 m;
- ✓ **Height:** 1.45 m;
- ✓ **Total width**: 2.5 m;
- ✓ **Operating width**: 2,4 m;
- ✓ **Weight**: 750 kg;
- ✓ **Number of teeth**: 28 retractable;
- ✓ **Average speed:** 20 km/h

The beach groomer also has two side deflectors to prevent objects raked up from escaping.

The vehicle requires just one driver.

Beach groomer

TASK

The surf rake was trialled in Martinique, as part of a call for expressions of interest, issued by ADEME to remove beached sargassum seaweed washed up on beaches.

These trials were inspected by SAFEGE to estimate:

- ✓ **The yield** (m^3 of seaweed collected per hour);
- ✓ **Advantages**;
- ✓ **Disadvantages**;
- ✓ **Areas for improvement.**

ESTIMATED YIELD

The beach groomer does not strictly harvest seaweed as it does not pick it up. It simplifies seaweed collection using other methods by forming piles or moving seaweed about the beach.

As such, no direct yield and can be estimated using this method.

ESTIMATED COST

The costs shown below are taken from data provided by the SEEN company and ADEME (March 2015).

<u>**Cost of equipment**</u>: (excl. tax and transport)

- ✓ **Standard beach groomer**: approximately €9,000 - 10,000 (excl. tax)
- ✓ **Tractor 100 cv 4x4 with frontal loader**: €50,000 (excl. tax).

<u>**Daily hire fee (excl. tax)**</u>

- ✓ **Tractor + Surf-Rake 600 HD + driver + maintenance**: €1,175 per day (price currently being updated).
- ✓ **Transport round trip**: €450

ADVANTAGES

- ✓ **Driver safety**: air-conditioned cabin reduces discomfort in hot weather. The high driving position also cuts the risk of exposure to H_2S,
- ✓ **Easy to manoeuvre** on the beach with low-pressure high load-bearing tyres (except in specific cases, see below).

DISADVANTAGES

- ✓ **Cannot harvest seaweed**, so needs a second piece of machinery or the addition of a claw bucket mounted on the tractor.
- ✓ The raking action **mixes up a lot of sand with the seaweed**, leading to a rise in the amount of sand collected when the seaweed is not already buried. This action tends to exacerbate beach erosion.
- ✓ **Not suitable for large seaweed strandings**. Large-scale stranding events are mainly targeted by harvesting requirements. However, their high density means they can be effectively harvested using other methods. The beach groomer's main advantage is that it can be used for low-density, scattered strandings over large areas for which collection requirements can be discussed.
- ✓ **Can get bogged down** on beaches with low load-bearing capacities (e.g. La Richer at Sainte Marie) despite the use of low pressure, high load-bearing tyres.
- ✓
- ✓ **Risk of breakages** when used on thick mats of seaweed, as happened on the trail site when springs and teeth were broken.
- ✓ **Non-selective harvesting**, picking up seaweed and rubbish (plastics, etc.) could be a problem for recycling processes.
- ✓ **Regular essential maintenance** to prevent corrosion.
- ✓ **Use limited** to beaches with room for manoeuvring and accessible from roads.
- ✓ **Driver training required before use**;
- ✓ **Risk of crushing sea turtle nests**

AREAS FOR IMPROVEMENT

The main areas for improvement identified from trials concern:

Sieving: Reducing the proportion of sand added to the seaweed when the beach groomer operates would make for more regular use and cut the risk of beach erosion.

The resistance of the groomer to prevent breakages.

CONCLUSION

From observations made during trials, the beach groomer does not appear to deliver significant improvements when dealing with large strandings. Indeed, thick layers of seaweed that cause health and environmental problems are already sufficiently assembled to be harvested by other methods. By contrast, the teeth lift large amounts of sand which combines with the seaweed when raking the beach. This adds weight to tipper truck loads and exacerbates erosion processes.

In addition, the beach groomer does not appear to be the right size to deal with the weight of seaweed.

The beach groomer appears better suited for use on scattered strandings where the goal is to make beaches visibly cleaner. This last scenario has however not yet been tested.

EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – BEACH GROOMER

IMAGES

Beach groomer undergoing trials – 10/08/2017

EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – LONG-REACH EXCAVATOR

GENERAL DATA

Field: Mechanised onshore seaweed collection
Equipment: Long-reach excavator
Company: various

EQUIPMENT

The excavator is a piece of heavy construction machinery, also known as a digger or long-reach excavator.

Excavators comprise a chassis on caterpillar tracks or tyred wheels topped with a cabin that rotates 360 degrees. The cabin also holds the engine, hydraulic lifting gear (pump, motor, cylinders), the driver's seat and equipment (arm, boom, swinging arm and bucket).

Long-reach excavator

Excavators come in all sizes but can be split into 4 categories:

- ✓ Mini-excavators (under 10 tonnes);
- ✓ Medium excavators (10 - 30 tonnes), the type of model used for these trials;
- ✓ Large excavators (30 - 100 tonnes);
- ✓ Mining or "production" excavators (100 tonnes +);

Similarly, their buckets come is a wide range of shapes and forms. Buckets observed during trials were:

- ✓ Digging buckets;
- ✓ Riddle buckets.

TASK

Long-reach excavators were observed in Martinique working to clear stranded sargassum seaweed from beaches.

Some clean-up operations were inspected by SAFEGE to estimate:

- ✓ **The yield** (m^3 of seaweed collected per hour);
- ✓ **Advantages**;
- ✓ **Disadvantages**;
- ✓ **Areas for improvement.**

ESTIMATED YIELD

The yield has been estimated based on the time to fill and empty the bucket together with the time to fill skips of a known size. The theoretical yield for one 1 m3 bucket is about 100 m3/h.

This volume nevertheless corresponds to a mix of sand and seaweed as this type of harvesting method is non-selective. On average, the amount of sand collected equates to 20-30% of total volume. This level varies considerably according to how thick the strandings are, bucket size and driver experience, etc.

ESTIMATED COST

The costs shown below are taken from data provided by ADEME and DEAL (2018).

Daily hire fee (excl. tax)

- ✓ **Long-reach excavator + driver + maintenance: €2,000 per day**

Average cost (excl. tax) compared to theoretical yield (excl. removal) for a 5-hour, uninterrupted day:

- ✓ per m^3 collected: **€2.6/m^3**.

These figures do not include additional costs for work required to return the sand to the site it was taken from. As a result, the total estimated cost is €20-40/m^3 of sand to be recovered, transported and spread on the beach

ADVANTAGES

- ✓ **High yields** in good conditions on the ground as the excavator is only intended to be used in the right conditions.
- ✓ **Driver safety**: air-conditioned cabin reduces discomfort in hot weather. The high driving position also cuts the risk of exposure to H_2S,
- ✓ Directly **loading** in a tipper truck without the need of an additional piece of machinery.
- ✓ **Can operate in shallow water from the shoreline.**
- ✓ **Easy to manoeuvre** on the beach with caterpillar tracks
- ✓ The excavator is a **versatile piece of machinery** and can be used for other tasks than just collecting sargassum.
- ✓ **Minimal operator numbers**: just one driver

DISADVANTAGES

- ✓ **Highly erosive to beaches,** with large amounts of sand being collected
- ✓ **Needs to be placed near a skip to empty the bucket**
- ✓ **Non-selective harvesting**, picking up seaweed and rubbish (plastics, etc.) could be a problem for recycling processes.
- ✓ **Regular essential maintenance** to prevent corrosion.
- ✓ **Driver training required before use**;
- ✓ **Risk of crushing sea turtle nests**

AREAS FOR IMPROVEMENT

There are three main areas for improvement to be studied:

- ✓ **Reducing beach erosion**: Developing more appropriate buckets (such as screening, grapple or claw buckets, etc.) and managing stocks removed would favour future work to restock beaches.
- ✓ **Introduction of a movement plan on beaches with sea turtle nesting sites**: During the nesting period, vehicle movements would be limited to the section of beach concerned by high tides. Movements on the upper part of the beach where turtles lay their eggs must be avoided.

CONCLUSION

Excavators are mechanised onshore and shoreline seaweed collection tools.

They achieve high harvesting yields (100 - 200 m3/h) for any type of stranding.

This collection method nevertheless constitutes one of the main source of beach erosion and, as such, has maximum impact on the environment when using digging or riddle buckets.

Special attention must be given to:

- ✓ **Good tipper truck rotations to ensure a skip is always present next to the excavator;**
- ✓ **The ability of tipper trucks to access stranding sites on low load-bearing beaches;**
- ✓ **Storage traceability of removed sargassum to recover and return the sand to the right site, as required (replenishing beaches)**

Training required to operate the vehicle.

Currently, the use of long-reach excavators with digging or riddle buckets should be avoided as far as possible due to their heavy environmental impact (erosion). These techniques nevertheless make it possible to work on areas inaccessible to other methods from the land (backs of bay, shorelines, etc.) and are suited to mass, well-rotten seaweed strandings.

IMAGES

Image of the erosive effects – Piles of sand from an excavator harvesting seaweed (Le Diamant – Martinique / Punta Cana – Dominican Republic)

Examples of screening or claw buckets

EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – SELF-PROPELLED HARVESTING VEHICLE

GENERAL DATA

Field: Mechanised onshore seaweed collection
Equipment: Self-propelled harvesting vehicle
Company: AXINOR

EQUIPMENT

The AXINOR self-propelled harvesting vehicle is a prototype mechanised seaweed harvester that combs the beach surface with tines attached to a treadmill to pick up seaweed and rubbish. The waste gathered is then transferred to the vehicle's 20 m³ hopper via a series of conveyors: a horizontal belt that takes the seaweed under the hopper and a lateral belt to fill it.

Self-propelled harvesting vehicle

The main features are show below (manufacturer's data):

- ✓ **Dimensions**: length 10 m, width 2.5 m, height 3.5 m
- ✓ **Tyres**: Low-pressure, high load-bearing tyres;
- ✓ **Operating depth**: Adaptable from 0 to 15 cm;
- ✓ **Hopper capacity**: 20 m3;
- ✓ **Speed**: 40 km/h
- ✓ **Tare weight**: 15 t;
- ✓ **Payload**: 15 t

The driver's cabin is air-conditioned and fitted with an H_2S gas detector and filters. The vehicle requires just one driver.

Self-propelled harvesting vehicle

TASK

The self-propelled seaweed harvester was trialled in Martinique, as part of a call for expressions of interest, issued by ADEME to remove beached sargassum seaweed.

These trials were inspected by SAFEGE to estimate:

- ✓ **The yield** (m³ of seaweed collected per hour).
- ✓ **Advantages**;
- ✓ **Disadvantages**;
- ✓ **Areas for improvement.**

ESTIMATED YIELD

The yield has been estimated based on the time taken by the vehicle to fill and empty a 20 m³ skip.

It was noted, on-site, that filling and emptying times were very quick:

- ✓ Approximately 8 min to fill a skip with a mat of fresh seaweed;
- ✓ About 1 min to empty it.

The yield depends on the distance travelled between the collection and emptying points, together with the density of the stranding on the beach.

An average cycle in good conditions takes roughly 12 minutes.

This equates to a **maximum theoretical collection yield of 80 to 100 m³/h** for fresh seaweed strandings (less than 48-hours old).

This theoretical volume applies when the vehicle is used in good conditions. The yield depends on, in particular:

- **Stranding type**: A consistent mat of seaweed spread out over a strip of beach lends itself to shorter filling times and fewer trips than for a scattered mat.
- **The nature of the seaweed**: Old seaweed compacted into banks means that the tines on the vehicle must be constantly adjusted, thus reducing the yield compared to fresh strandings. There is also the risk of the conveyor belts jamming when handling the compacted seaweed.
- **Travel distance** between the harvesting and emptying points. It should be noted that when disposing on the seaweed in tipper trucks, having a truck always on-site cannot be guaranteed due to the lengthy travel time to empty the skip.

The best operational set-up for the vehicle is handling fresh seaweed (less than 48-hours old), 10-80 cm thick.

Emptying the collection skip

ESTIMATED COST

The costs have been taken from data provided by AXINOR and ADEME (March 2015).

<u>**Cost of equipment**</u>: (excl. tax and transport)

- **Self-propelled harvester**: €341, 000 (excl. tax)

ADVANTAGES

- **High yields** in good conditions on the ground The vehicle should only be used in suitable conditions.
- The vehicle's **large hopper** limits the number of round-trips between the beached seaweed and the collection skip, leading to lower impact on the beach from vehicle movements.
- **Good mobility** on beaches due to low-pressure, high load-bearing tyres (except in specific cases - see below). A large seaweed stranding does not hamper vehicle mobility. In addition, the vehicle can operate reasonably far from the collection skip without the need to relocate it during collections.
- **Driver safety**: air-conditioned cabin reduces discomfort in hot weather. The elevated driving position and built-in filters eliminates the risk of exposure to H_2S.
- The hopper can be **emptied** directly into a tipper truck, thereby avoiding the need of additional machinery.
- **Vehicle can operate in shallow water** (max 40 cm). Speed may need to be altered to reduce the risk of the conveyor belts jamming (see below).
- **Lower staffing requirements**: one driver to operate the self-propelled harvester (plus possible additional drivers to remove the seaweed from the site in tipper trucks).
- **Maintains a thin layer** of seaweed (roughly 5 - 10 cm), to sustain a positive ecological function played by the seaweed on the upper foreshore.
- **Low amount of sand collected**: Around 1% of the total amount and less than 5% of weight for $1 m^3$ of fresh seaweed. This helps limit beach erosion when there are regular clean-up operations.
- **Vehicle can be driven** on roads and does not require a truck/trailer.
- Provides a **visibly 'clean' result** on beaches able to withstand the load.

DISADVANTAGES

- ✓ **Risk of getting bogged down** or ruts forming on some beaches unable to support the weight of machinery, despite the use of low-pressure, high load-bearing tyres.
- ✓ **Risk of lateral conveyors jamming** when harvesting heavy deposits of old, compact or soaking seaweed.
- ✓ **Non-selective harvesting**, picking up seaweed and rubbish (plastics, etc.) could be a problem for recycling processes.
- ✓ **Essential maintenance** needed on a regular basis to prevent corrosion (rinse-down with fresh water after each use and greasing of components once a week).
- ✓ **Use limited** to accessible beaches with room for manoeuvring and accessible from roads.
- ✓ **Risk of crushing sea turtle nests when moving about on the upper part of the beach.**
- ✓ **Can contribute to beach erosion** if the remaining thin layer (5 - 10 cm) is removed. In this case, there is a marked rise in levels of sand collected.

AREAS FOR IMPROVEMENT

This is a prototype vehicle and following trials, the main areas for improvement focus on:

- ✓ **Load-bearing capacity**: The vehicle got bogged down on some beaches. This either brought harvesting to a halt or caused partial, localised damage to the beach (ruts or damage to mounds between the beach and land, etc.). Using caterpillar tracks, reducing the size of the vehicle or increasing the number of wheels could be considered.

- ✓ **Tackling conveyor jams**:
    - Strengthen the conveyor fins to stop them deforming when they encounter a heavier patch of seaweed;
    - Central and lateral conveyor speed regulator: If the lateral conveyor was faster than the central treadmill, the seaweed would be more evenly distributed and larger clumps of seaweed would not form;
    - Reduce the speed when harvesting old, rotting seaweed strandings (>48h) to prevent a sudden, large intake of seaweed.
    - On future vehicles: Remove the lateral conveyors and replace them with a sloping central belt.

CONCLUSION

The self-propelled harvesting vehicle is a mechanised onshore seaweed collection prototype.

It delivers collection yields of around 80 - 100 m^3/h in good operating conditions:

- ✓ **Beach accessible to heavy machinery with enough load-bearing capacity.**
- ✓ **Fresh, dense strandings (less than 48 h old) 10 to 80 cm thick.**

This system also offers good mobility on roads and beaches and causes little physical damage to beaches (small proportion of sand collected with the seaweed).

Specific attention must be given to risks of:

- ✓ **Lateral conveyor jams when harvesting compacted or soaking seaweed (heavy weight).**
- ✓ **Getting stuck on beaches that cannot take the weight of the vehicle.**

Training required to operate the vehicle.

The self-propelled harvesting vehicle is most effective for cleaning up large-scale strandings.

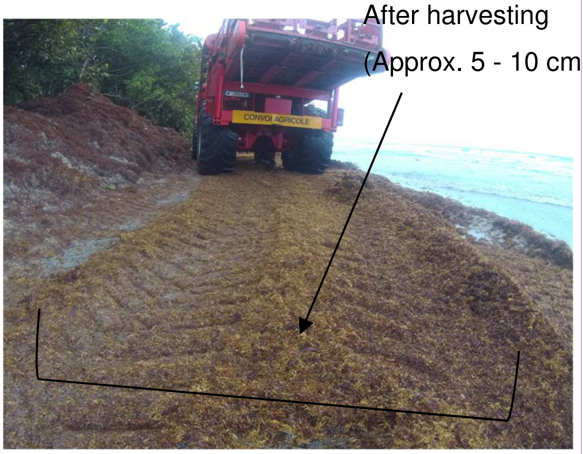
EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – SELF-PROPELLED HARVESTING VEHICLE

IMAGES

Pointe Faula before and after harvesting

Le Diamant before and after harvesting



EVALUATION OF SARGASSUM HARVESTING

FACTSHEET - SURF RAKE

SAFEGE Ingénieurs Conseils

ADEME Agence de l'Environnement et de la Maîtrise de l'Energie

GENERAL DATA

Field: Mechanised onshore seaweed collection
Equipment: BARBER 600HD Surf Rake
Company: SEEN

EQUIPMENT

The surf rake is a tractor-towed machine with tines fitted to a conveyor belt that rakes up seaweed and rubbish from the beach surface. The model tested during trials was a BARBER 600HD, fitted with a 2,3 m^3 storage hopper.

BARBER 600HD Surf Rake

The main features are show below (manufacturer's data):

- ✓ **Pulling power**: 4x4 agricultural tractor (80 cv minimum);
- ✓ **Tyres**: low-pressure high load-bearing;
- ✓ **Operating width**: 2.14 m;
- ✓ **Operating depth**: Adaptable from 0 to 15 cm;
- ✓ **Hopper capacity**: 2.3 m^3;
- ✓ **Hopper lifting height**: 2.75 m;
- ✓ **Service weight**: 1,800 kg;

The tractor can also be fitted with a frontal claw bucket to lift any obstacles or large or compact items of rubbish, or to gather very thick mats of sargassum.

The driver's cabin is air-conditioned and fitted with an H_2S gas detector. The vehicle requires just one driver.

Surf rake – Claw bucket

TASK

The surf rake was trialled in Martinique, as part of a call for expressions of interest, issued by ADEME to remove beached sargassum seaweed.

These trials were inspected by SAFEGE to estimate:

- ✓ **The yield** (m^3 of seaweed collected per hour);
- ✓ **Advantages**;
- ✓ **Disadvantages**;
- ✓ **Areas for improvement.**

ESTIMATED YIELD

The estimated yield is based on the time taken by the surf rake to fill and empty its 2.3 m^3 hopper.

It was noted, on-site, that hopper filling and emptying times were very quick:

- ✓ Approx. 1 min to fill;
- ✓ Roughly 40 s to empty.

The yield is therefore highly dependent on the distance between collection and emptying points. The average travel time for the set-ups tested during trials was the same as the filling time.

The average time recorded for a cycle in good conditions was 4 - 5 min.

Given optimal conditions, the maximum yield recorded in the set-ups tested during trials was approximately 40 m3/h.

This theoretical volume applies when the vehicle is used in good conditions. The yield depends on, in particular:

- **Stranding type**: A consistent mat of seaweed spread out over a strip of beach lends itself to shorter filling times and fewer trips than for a scattered mat.
- **Nature of seaweed**: Old seaweed compacted into banks means that the tines on the vehicle must be constantly adjusted, thus reducing the yield compared to fresh strandings.
- **Travel distance** between the harvesting and emptying points. As the hopper's storage capacity was relatively small, the surf rake will need to complete many round-trips for large strandings. It should be noted that when disposing on the seaweed in tipper trucks, having a truck always on-site cannot be guaranteed due to the lengthy travel time to empty the skip.

The best operational set-up for the surf rake is handling fresh, dense or scattered seaweed (less than 48-hours old), 20 -30 cm thick. Above this, the surf rake's mobility can be compromised. It should therefore be regularly used on-site to avoid too much seaweed building up on the beach.

Using the surf rake together with a **claw bucket** partly helps to adapt to these unfavourable conditions:

- Good results for harvesting banks of seaweed;
- Option of heaping seaweed on the ground if no tipper trucks available, then removing it and loading it in a truck using the bucket.

Loading a tipper truck using a bucket

ESTIMATED COST

The costs shown below are taken from data provided by the SEEN company and ADEME (March 2015).

<u>**Cost of equipment**</u>: (excl. tax and transport)

- **Surf Rake 600 HD**: €53,480 (excl. tax);
- **Standard tractor-towed Beach Groomer**: €8,960 (excl. tax);
- **Tractor 100 cv 4x4 with frontal loader**: €50,000 (excl. tax);

<u>**Daily hire fee (excl. tax)**</u>

- **Tractor + Surf-Rake 600 HD + driver + maintenance**: €1,175 per day (price currently being updated).
- **Transport round trip**: €450

<u>**Average cost (excl. tax) compared to theoretical yield (excl. removal) for a 5-hour, uninterrupted day**</u>:

- per m³ of fresh seaweed harvested: approx. **€8 per m³**.
- per tonne of fresh seaweed collected: approx. **€24 per tonne**

ADVANTAGES

- **Yield:** In good conditions on-site, the surf rake should achieve 30 m3/h. as the excavator is only intended to be used in the right conditions.
- **Low levels of sand collected**: Approx. 1.5% in terms of volume and 5% in terms of weight for 1m³ of fresh seaweed. This helps significantly limit beach erosion with regular clean-ups.
- **Driver safety**: air-conditioned cabin reduces discomfort in hot weather. The high driving position also cuts the risk of exposure to H_2S,
- The hopper can be **emptied** directly into a tipper truck, thereby avoiding the need of additional machinery.
- **Versatility** for different types of seaweed strandings by adding a claw bucket, with the potential of non-beach applications (cleaning up green spaces).
- **Vehicle can operate in shallow water** (max 40 cm).
- **Good mobility** on beaches due to low-pressure, high load-bearing tyres (except in specific cases - see below). Excessive strandings can sometimes impeded the movement of the surf rake. The surf rake can operate reasonably far from the collection skip without the need to relocate it during collections.
- **Lower staffing requirements**: The surf rake requires one driver (plus possible additional drivers to remove the seaweed from the site in tipper trucks).
- Provides a **visibly 'clean' result** on beaches able to withstand the load

DISADVANTAGES

- ✓ **Can get bogged down** on beaches with low load-bearing capacities (e.g. La Richer at Sainte Marie) despite the use of low pressure, high load-bearing tyres.
- ✓ The surf rake's **'limited' storage capacity** in its hopper means numerous round-trips must be made when harvesting dense strandings.
- ✓ **Several sweeps are needed** to clear very thick mats of seaweed.
- ✓ **Non-selective harvesting**, picking up seaweed and rubbish (plastics, etc.) could be a problem for recycling processes.
- ✓ **Regular essential maintenance** to prevent corrosion.
- ✓ **Use limited** to accessible beaches with room for manoeuvring and accessible from roads.
- ✓ **Driver training required before use**;
- ✓ **Risk of crushing sea turtle nests when moving about on the upper part of the beach.**

AREAS FOR IMPROVEMENT

The main areas for improvement identified from trials concern:

- ✓ **Load-bearing capacity**: The surf rake got bogged down on some beaches. This either brought harvesting to a halt or caused partial, localised damage to the beach (ruts or damage to mounds between the beach and land, etc.). between the beach and land, etc.). In these cases, the use of caterpillar trackscould be considered.
- ✓ **Storage volume**: a larger volume on

CONCLUSION

The surf rake is a mechanised method for onshore clean-ups.

It can achieve yields of approximately 40m^3/h in optimal operating :

- ✓ **Beach accessible to heavy machinery with enough load-bearing capacity.**
- ✓ **Fresh dense or scattered strandings (less than 48 hours) less than 30 cm thick.**

This system also offers good mobility on roads and beaches and causes little physical damage to beaches (small proportion of sand collected with the seaweed). Provides a visibly 'clean' result by efficiently collecting seaweed in thin layers.

Special attention must be given to:

- ✓ **The risk of getting bogged down in low load-bearing capacity beaches.**
- ✓ **The distance between the stranding and tipper truck as numerous round trips hugely impact on operational yields.**

The surf rake is mainly used to maintain beaches and must be used regularly in the event of strandings to avoid too much seaweed building up on the beach.

IMAGES

Anse Cafard beach (Le Diamant) before and after harvesting

Bourg du Vauclin before and after harvesting

Emptying the hopper

EVALUATION OF SARGASSUM HARVESTING
FACTSHEET – MANUAL ONSHORE COLLECTION

GENERAL DATA

Field: Manual onshore collection
Equipment: Forks, rakes and wheelbarrows
Association: CAID – Green Brigades

EQUIPMENT

"Green Brigades" are an employability scheme to assist sargassum clean-up operations, maintain rivers and protect and safeguard natural heritage.

In Martinique, the Green Brigade activities are managed by the CAID PATRIMOINE ASSOCIATION.

Five teams, each with around twelve people were working in the Cap Nord and Espace Sud areas of the island during the trials.

A Green Brigade team at Vauclin

The teams are equipped with:

- ✓ **Forks;**
- ✓ **100l wheelbarrows;**
- ✓ **Gloves, boots and hats;**
- ✓ **An H_2S gas detector (1 - 2 per team);**

The teams have no mechanised equipment (diggers, excavators, etc.). They can however be supplied to green brigade clean-ups to help remove collected seaweed.

In should be noted that each team member will eventually have their own H2S gas detector, together with a record of gas concentrations they are exposed to (exposure monitoring) and a gas mask for working in H2S-prone areas.

TASK

The "Green Brigades" in Martinique were tasked with removing seaweed washed up on the island's beaches.

SAFEGE conducted a number of inspections on clean-up operations to estimate:

- ✓ **The yield** (m^3 of seaweed collected per hour);
- ✓ **Advantages;**
- ✓ **Disadvantages;**
- ✓ **Areas for improvement.**

ESTIMATED YIELD

Yields were estimated based on the number of wheelbarrow loads emptied during a given period of time by **6 people equipped with 3 forks and 3 wheelbarrows**.

The average volume contained in a wheelbarrow was estimated in two ways:

- ✓ Theoretical volume of a wheelbarrow;
- ✓ Weight/volume ratio (1 m3 of fresh seaweed = 300 kg).

It was observed on-site that one team of 6 people, working in pairs managed to collect an average of 108 wheelbarrow-loads per hour containing an average of 70 kg per wheelbarrow (wet seaweed).

The yield achieved by this team arrangement varied between **11 - 16 m^3/hour.**

ESTIMATED COST

The costs shown below are taken from data provided by CAID PATRIMOINE and equipment retail outlets.

<u>**Equipment costs (incl. tax)**</u>:

- ✓ **Wheelbarrows:** approx. €55 each
- ✓ **Forks, buckets:** approx.€15 - 20 per tool
- ✓ **H_2S gas detector:** €100 - €400 according to model
- ✓ **Gloves, boots, overalls:** approx. €100 per person

<u>**The cost per hour of an employability scheme worker (ACI)**</u>:

- ✓ Approximately €35 per hour.

<u>**Value for money: Average cost compared to yield for one employee (excl. cost of purchasing equipment)**</u>:

- ✓ per m^3 of fresh seaweed collected: **€15.5/m^3**.

- ✓ per tonne of fresh seaweed collected: **€51.6 per tonne**

ADVANTAGES

- ✓ **Yield**: One team of 12 people working in pairs can collect 22 to 32 m^3/h.
- ✓ **An environmentally-friendly method**: Areas to be clean can be targeted. It poses no risk of beach subsidence or danger of crushing sea turtle nests and the equipment used does not harm the beach.
- ✓ **Low amount of sand collected**: Around 1% of the total amount and less than 5% of weight for 1m^3 of fresh seaweed. This significantly limits beach erosion with regular clean-up operations.
- ✓ **Easy access**: Green brigades can access beaches off-limits to vehicles.
- ✓ **Smart gathering**: manual clean-ups can sort and separate seaweed and large items of waste (plastic bottles, etc.) on the beach.
- ✓ **Versatility** for different types of seaweed strandings, with the potential of non-beach applications (cleaning up green spaces).
- ✓ **Low-cost equipment**
- ✓ **A neat and tidy result**
- ✓ **Social inclusion** role to partly address employment issues in the case of the employability beach clean initiatives.

DISADVANTAGES

- ✓ **Needs large numbers of people:** The yield is directly related to the number of people on-site.
- ✓ **Significant health risks**: Green Brigades are more exposed to heat and H_2S, which limits their performance in the event of large quantities of rotting seaweed, with resulting risks of feeling unwell during collection operations. First-aiders should be stationed on-site.
- ✓ **No direct disposal**: Green Brigades have no tools to directly fill skip trucks. They must first deposit the seaweed in piles to then be gathered by heavy machinery to completely rid the site of seaweed.

AREAS FOR IMPROVEMENT

There are two main areas for improvement that need to be studied:

- ✓ **Change team arrangements**: It would be useful to test various team set-ups (e.g. in trios, with one person collecting and two people wheelbarrowing the seaweed, to see if this improves yields.
- ✓ **Supervising the removal of seaweed in cases where it is taken to another site**. As the green brigades are not equipped with removal equipment, the seaweed gathered ends up being stored at the top of the beach. Removing these piles of seaweed must be systemically organised with the relevant authorities to avoid the build-up of seaweed and ensuing foul smells (odours and effects on the vegetation, etc.).

CONCLUSION

Manual clean-ups have many advantages such as:

- ✓ **Very low environmental impact (erosion, ruts, crushing sea turtle nests, etc.).**
- ✓ **Ability to operate on a wide range of sites.**
- ✓ **Low-cost equipment**
- ✓ **Social inclusion/employability Role.**

Yields from this method nevertheless remain highly dependent on the number of people employed, with estimated yields of 2 - 2.5 m^3 per hour per person.

Manual collections do however come with significant occupational health risks. Workers are exposed to the heat and H2S and can experience nausea and headaches, etc.
When H2S concentrations exceed alert thresholds (5 ppm), workers must wear gas masks, while above 10 ppm, they must leave the collection area.

Good team supervision is therefore vital.

This type of collection method is best suited to sites that are inaccessible to mechanised harvesting vehicles.

IMAGES

A team of 8 workers– Before and after 2 hours cleaning-up – Pointe Faula (Vauclin)

Anse aux bois (Sainte Anne)

EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – HARVESTING BARGE AT SEA

GENERAL DATA

Field: Mechanised offshore collection
Equipment: Harvesting barge at sea
Company: ALGEANOVA

EQUIPMENT

The harvesting barge used by ALGEANOVA is a prototype motorised vessel which harvests sargassum mats offshore (close to the coast) on a tilted conveyor belt as the barge moves through the water. The seaweed is then stored in 1.5 m^3 big bags at the rear of the vessel. It can hold up to 35 big bags, i.e. 52 m^3 (approx. 15-20 tonnes).

Harvesting barge at sea

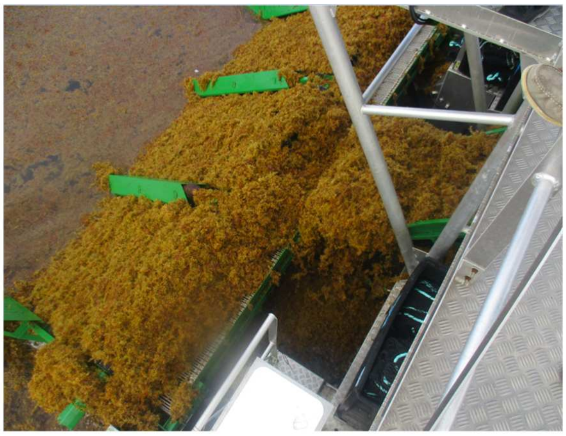
The main features are show below (manufacturer's data):

- ✓ **Speed in transit**: approx. 5-7 knots
- ✓ **Harvesting speed**: approx. 2 knots
- ✓ **Belt collection width**: 6m
- ✓ **Operating depth**: Adaptable from 0 to 30 cm;
- ✓ **Storage capacity**: 45 - 60 m^3 (approx. 15-20 tonnes);
- ✓ **Draft, barge empty**: 1 m;
- ✓ **Draft, barge full**: 1.5 m.

The barge is also equipped with a mini-crane to move the big bags around the barge and offload them (capacity: 500 kg at 4 m).

The crew comprises a captain, a crane operator and 2 - 3 workers

View of the conveyor belt in action



TASK

The harvesting barge was trialled at Punta Cana (Dominican Republic) in agreement with ALGEANOVA and ADEME, to present their equipment and solutions developed to tackle sargassum strandings.

These trials were inspected by SAFEGE to estimate:

- ✓ **Yield**
- ✓ **Advantages**;
- ✓ **Disadvantages**;
- ✓ **Areas for improvement.**

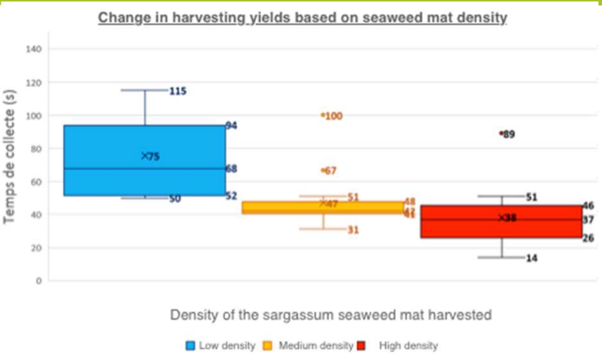
ESTIMATED YIELD

There are two estimated yields:

- ✓ **The collection yield,** independent of limitations due to storage volume, transit and emptying times.
- ✓ **Overall yield,** including limitations due to storage volume, transit and disposal times.

The collection yield has been calculated according to time taken to fill 53 1.5 m^3 big bags, taking into account the density of the seaweed mat collected and its thickness (H) (visual estimate).

- ✓ **Low density**: The mat does not cover the whole surface (H: approx. 0.1m).
- ✓ **Medium density**: the mat almost covers all the surface (H: approx. 0.1 - 0.2 m).
- ✓ **High density**: The mat covers the whole surface (H: > 0.2 m).



It was observed on-site that average filling time varies according to the density of the seaweed mat.

- ✓ **Low density**: 75 seconds, or **72 m³/h**.
- ✓ Medium density**: 47 seconds, or** **115 m3/h.**
- ✓ **High density**: 38 seconds, or **142 m³/h.**

In optimal user conditions, (medium to high density), the unadulterated collection rate is between **115 and 140 m³/h**.

The overall yield features a fixed component (harvesting and emptying times) and a variable factor (journey times depending on the distance between harvesting and emptying points).

- ✓ **The average collection time observed to harvest 30 big bags was** 33 min, or 83 m³/h
- ✓ **The average time to empty a big bag was** 82 seconds, or 41 min.

As such, the fixed component of the overall yield for 30 big bags (45 m³) is 1 hour and 15 min.

During the tests, the travel time between the collection and disposal points was 15 min, resulting in an overall yield of 45 m³/1 hour 45 min (26 m³/h).

Assuming four collection cycles a day, the prototype can harvest approximately 180 m ³of sargassum per day, or roughly 60-70 tonnes of fresh drained seaweed.

The prototype's overall yield depends on:

- ✓ **Density**: Dense mats of seaweed significantly reduce collection times.
- ✓ **Nature of seaweed**: Old, rotting seaweed tends to jam the conveyor belts and temporarily bring harvesting to a halt.
- ✓ **Travel distance** between the harvesting and emptying points.

ADVANTAGES

✓

- ✓ **High yield** when harvesting high density mats of seaweed. The vessel should only be used in these circumstances when operating.
- ✓ **No effects on beaches:** As seaweed is collected offshore, beaches are protected from mechanised processes (erosion, rutting, crushing sea turtle nests, etc.).
- ✓ **Collection before rotting:** As the seaweed is collected at sea, the decomposition process (and resulting H2S emissions) has not started.
- ✓ Big-bags can be directly **offloaded** into a tipper truck, thereby avoiding the need of an additional vehicle or machine.
- ✓ **Opportunity to work close to shore** as the draft is just 1.5 when loaded.
- ✓ **Ease of movement**, to directly access several nearby bays or beaches from one site.
- ✓ **A "clean" sand-free harvesting operation** which simplifies possible processing and recycling operations.

DISADVANTAGES

- ✓ The barge's **'limited' storage capacity** requires numerous return-trips and drops in yield.
- ✓ **Non-selective harvesting**, picking up seaweed and rubbish (plastics, etc.) which requires sorting if material is to be recycled or re-used.
- ✓ **Possible conveyor** belt jams when harvesting highly compacted seaweed (e.g. when well-rotted).
- ✓ **Regular essential maintenance** to prevent corrosion.
- ✓ **The barge must be combined** with a protection technique (floating barrier) to optimise harvesting and prevent seaweed washing up on the shoreline.
- ✓ **Operational area limited** by the barge's transit speed and in areas protected by coral reefs. The barge cannot operate by the beach due to its draft.

SAFEGE Ingénieurs Conseils

ADEME Agence de l'Environnement et de la Maîtrise de l'Energie

COSTS

At the present time, ALGEANOVA has no plans to lease the prototype on a daily basis but intends introducing an **annual maintenance contract**, including installation of the floating barrier, maintenance and collecting seaweed along the length of the barrier using the barge. As this is a prototype version, the model that will eventually be marketed will be new (version 2) and cost roughly €980,000 excl. tax.

AREAS FOR IMPROVEMENT

This is a prototype vehicle and following trials, the main areas for improvement focus on:

- ✓ **Conveyor belt operations**: Widening the conveyor belt mouth to 9 m and reducing the number of belts will raise collection yields, enable the barge to harvest seaweed along a floating barrier in one sweep and significantly cut the jamming problems where two conveyor belts meet.
- ✓ **Increasing the size of the big bags to 3 t (approx. 6.5 m3)**: This bigger size will significantly reduce emptying times using the crane.
- ✓ **Introducing 30 t mobile storage hoppers, separate from the harvesting barge.** Once filled, these storage hoppers can be uncoupled from the harvesting barge and taken to the disposal point. A second unit can then take the place of the first and the collection can continue. This innovation means that the barge could remain in the harvesting area for the entire time it is used (10 to 12 hours) and the number of storage units geared to the distance to be covered and the seaweed mat density.

It may also be possible to improve the efficiency of these barges outside sargassum stranding events by developing tools designed for other marine operations (dredging, installing floating barriers, etc.).

CONCLUSION

This pick-up barge is a prototype offshore mechanised harvester (close to the shoreline).

It achieves an overall yield of approximately 30 m^3/h for dense seaweed strandings close to a disposal point (figure recorded for a one-way journey of about 2 km).

This yield could be improved but remains restricted by

- ✓ **The speed the barge can travel at.**
- ✓ **Barge storage capacity.**
- ✓ **Barge emptying time.**

The system ensures sargassum strandings have no adverse effect on the coastline.

For optimal operating conditions, this method must be combined with a seaweed concentrator system (floating barrier) to gather the seaweed together in an area with sufficient draft and, in doing so, reduce the surface area to be cleared offshore.

IMAGES

EVALUATION OF SARGASSUM HARVESTING

FACTSHEET – ALGEANOVA FLOATING BARRIER

GENERAL DATA

Subject: Coastal protection
Equipment: ALGEANOVA anti-sargassum floating barrier
Company: ALGEANOVA

developed by ALGEANOVA is to protect vulnerable areas of the coast by keeping sargassum at sea and stop it washing up on the shore.

ALGEANOVA anti-sargassum barrier

TASK

The anti-sargassum barrier developed by ALGEANOVA was trialled opposite the Westin Hotel in Punta Cana (Dominican Republic) in agreement with ALGEANOVA and ADEME to present their equipment and solutions developed to tackle sargassum strandings.

These trials were inspected by SAFEGE to estimate:

- ✓ **Advantages**;
- ✓ **Disadvantages**;
- ✓ **Areas for improvement.**

EQUIPMENT

This barrier comprises 6 m modules (9 m for the finalised version) that can be joined together. It includes:

- ✓ **A 350 mm diameter inflatable boom**, protected by a flexible PVC sleeve and a second micro-mesh coating (to protect against floating debris) .
- ✓ A **1 m skirt** below the barrier made of 25 mm diameter textile mesh.
- ✓ **It is anchored every 3m** (helix moorings and buoys subject to substrate) with a 20mm chain linking the barrier anchoring points weighing 7kg per metre.
- ✓ **A dual fastening system between modules** using Velcro and shackles and thimbles which help stop seaweed passing through while ensuring the barrier remains stable under the weight of seaweed and sea conditions (shackles).

View of a module and fastener

The starting point of the barrier can be set up:

- ✓ Directly from the beach by installing a fixed structure to prevent seaweed circumventing the barrier.

View of a barrier starting on the beach

- ✓ From a cliff using a vertical rail to attach the modules, enabling the barrier to rise and fall with the tide.
- ✓ At sea, with no specific structure.

At the time of the inspection, it was noted that the mesh skirt had started to be colonised by seaweed.

Start of colonisation

This colonisation will ultimately impact on performance (additional weight, wear and tear, net mesh clogged up, etc.). The **PROJINOVA Cleaner** is a vessel equipped with two rotating brushes that has been specifically designed to maintain the mesh net and prevent the build-up of marine life on the equipment. Special modules at each end of the barrier enable the cleaner to latch on to it, without having to dismantle it.

According to ALGEANOVA, cleaning the barrier once a month is sufficient.

PROJINOVA Cleaner

ADVANTAGES

- ✓ **Protects the coastline from strandings**. Just a small amount of seaweed managed to get through the barrier and reach the shore. The amount of seaweed not trapped by the barrier is sufficiently small to decay naturally and play a positive ecological role at the top of the foreshore.
- ✓ **Can be started from the beach or a cliff edge,** with special anchorings**.**
- ✓ **Its 1 m skirt retains most of the seaweed**, which tends to thicken when its density rises (approx. 0.6 - 0.7 m recorded).
- ✓ **Plays a FAD role** (fish-aggregating device) by maintaining a mat of un-decomposed seaweed on the surface.
- ✓ Anchor points at regular intervals and the weight of the chains **maintain the skirt in a vertical position** which prevents any marine life becoming trapped. The mesh size is sufficiently small (25 mm diameter) to prevent adult sea turtles becoming trapped.
- ✓ **Reduction in pressure linked to currents** acting on the barrier due to the mesh skirt, which enables water to circulate.

- **An accretion effect** (extending the beach) was initially observed. This may be due to the barrier reducing the swell in the protected area.
- **Limited storage:** As the booms are inflatable, transporting and storing the barrier onshore does not require a large area.
- **Simple deployment and removal** once the anchor points have been installed, as the barrier is linked to by shackles.

DISADVANTAGES

The barrier's drawbacks are generic and apply at all similar equipment:

- **Deploying the barrier is subject to the physical environment and sea conditions**. It also depends on bathymetry, the nature of the seabed, currents and swell, etc. All these parameters must be accounted for to ensure the anchor points are correctly sized and the modules properly positioned.
- **Essential maintenance** to prevent damage from flora and fauna attaching themselves to the barrier (colonisation) and mechanical wear and tear. According to the manufacturer, brushing down the mesh net once a month is sufficient to prevent colonisation.
- **Combination necessary with a technique to harvest trapped seaweed** to prevent seaweed building up along the barrier. A large build-up of seaweed on the barrier**,** according to wind, current and swell conditions, can result in considerable pressure in certain places along the barrier, and the risk of it splitting. If this happened the barrier would be rendered useless.
- **Necessarily removing it in poor wind and sea conditions** could damage the barrier. According to the manufacturer, the barrier must be removed under the following conditions:
  - Wind: 25 knots
  - Swell: 1.5 m
- **Possible alterations to sea depths (bathymetry) from scouring under the barrier at shallow depths**. Increased sea depths were recorded in front of the barrier at Punta Cana as it was installed in shallow water (approx. 1.7 m deep compared to 2.5 m underneath the barrier), probably due to changing currents.

COSTS

The costs shown below are taken from data provided by the manufacturer and are for indicative purposes only:

- **Cost of the floating barrier** (excl. anchoring, installation and transport): approx. €130/ml excl. tax
- **Supply and fitting anchor points, including connecting the barrier together: approx. €35,000/100ml**
- **Cost of Projinova Cleaner**: €150,000

AREAS FOR IMPROVEMENT

No specific problem with the equipment was detected during the inspection. Indeed, ALGEANOVA has made numerous changes to the barrier since its initial version (2014-2015).

CONCLUSION

No specific faults were recorded with the anti-sargassum barrier during the trial period (24-30 May) and it fulfilled its role despite regular arrivals of seaweed.

In addition to its role as a barrier, the equipment also provides a FAP effect by maintaining a floating bank of seaweed. The skirt get colonised by seaweed and causes a small ecosystem to develop. It appears that installing such a barrier also causes some erosion underneath it (at approx. 1 m) and an accretion effect on beaches located in the protected area.

Regular brushing of the mesh skirt (about once a month) and collecting seaweed (subject to stranding) is required to maintain the barrier's integrity, <u>regardless of the type of floating barrier installed.</u> A special cleaning vehicle with brushes has been designed for the barrier enabling rapid maintenance of long sections to be undertaken.

IMAGES

View of the barrier

View of the barrier

Shackle to connect two modules together

Anchor point