Baltic beach wrack — challenges for sustainable use and management

preliminary draft May 2020

Tool Kit

CONTRA
BALTIC BEACH WRACK
CONVERSION OF A NUISANCE TO A RESOURCE AND ASSET

Interreg
Baltic Sea Region

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Foreword

"As long as we have to compete with wide, pristine and white catalogue beaches, we have to present our beaches to tourists in the same way" (quote from a German spa manager Markus Frick, Island of Poel). Meeting public expectations of 'clean' recreational beaches is an ongoing challenge for coastal communities. There is no doubt that beach wrack (cf. inbox), as a natural part of coastal ecosystems, is often regarded as a nuisance, particularly when it lands unexpectedly and in large quantities on beaches. It can cover beaches for weeks, rotting to a smelly soup that leaches back into the water. Consequently, beach wrack can be an annoying problem particularly to those whose economies rely on beach tourism. During the summer season, it is already being regularly removed as part of expensive beach cleaning routines in most touristic regions along the southern and western Baltic Sea coast. But again and again the question is raised: what can be done with all the collected biomass that is invariably at differing stages of decay and comprises of 50–80 % sand? Could it be used as a resource rather than being disposed of as waste?

The discussion about beach wrack treatment is not new, having been pursued, mostly on a local basis, during various past projects. Some solutions have already been found and applied, but they remain local and fragmented. Local authorities are trying hard to independently find affordable, legal and worthwhile use options for this biomass, but are being restricted by regulatory barriers, the resources that can be spent, a lack of knowledge and cooperation.

We, the partnership of the EU-project CONTRA (**CO**nversion of a **N**uisance **T**o a **R**esource and **A**sset; 2019–2021) recognised from the outset that beach wrack management is not straight forward and needs a wide-ranging concept that transcends the boundaries of municipalities, regions and countries. Consequently, within CONTRA we gathered the knowledge and built the capacity required to exploit the potential of utilising beach wrack for the whole Baltic Sea region.

The challenge of beach wrack removal is to find a balance between public demand for 'clean' beaches, environmental protection and the economy. To address this and to balance opposing interests, CONTRA conducted a comprehensive evaluation of all perspectives relating to beach wrack management on national as well as international levels. The project consortium comprised of public authorities, businesses, academia and NGOs from six countries (DK, DE, EE, PL, SE, RU) covering marine systems, coastal tourism, sustainable development as well as administrative structures of the Baltic Sea region.

Different aspects of beach wrack removal and usage have been studied thoroughly. A set of seven case-studies has been described in detail, and includes an overview of their concept applicability. Additionally, ideas for sustainable options for pollution and nutrient remediation of the Baltic Sea have been put forward.

'The results of our work are presented in four thematically in-depth analyses (main reports).

Socioeconomics | Ecology | Business | Technology

Beach wrack – what is it?

There was some debate over the terms used to describe material that is washed ashore by the sea and deposited onto our beaches. Of the many terms that exist in national languages of Baltic countries, some are colloquial, some are used interchangeably even on a local level and others are used in several different countries. The terminology does not seem so important at first glance, however it plays a major role in the discussion when it comes to processing the material, e.g. with or without litter. From an extensive literature search we are able to identify the two terms that are most commonly used: beach cast and beach wrack. Both refer to the material that can be found all over the world in the swash zone, in lines along the foreshore and sometimes at the back of the beach, especially after storms. The amount and composition varies depending on the season, coastal landform, offshore substrates (determining algae/seagrass growth), currents, tidal forces, wind and wave action.

Thus, we propose the following interpretations for better understanding of our reports: Beach cast as an umbrella term for all washed up material consisting of beach wrack as the largest component, terrestrial debris, litter and living animals that inhabit it, but excluding materials such as sand, stones or pebbles. And beach wrack as purely the marine organic component of beach cast that originates from the sea, e.g. torn off seagrass, macro- and microalgae, shells, dead fish etc.

Since it is very difficult to mechanically collect "pure" beach wrack from beaches without sand, we additionally refer to it as being "collected beach wrack", particularly in relation to processing and treatment of the material.

This "**Tool kit**", covering practical aspects of beach wrack management, provides guidance for local and regional decisions makers. It serves as both a reference as well as a decision aid to help practitioners convert current beach wrack management schemes into more sustainable solutions.

Additional reports/documents relating to beach wrack management are available on our project website at *https://www.beachwrack-contra.eu/* including:

- **Legal aspects of beach wrack management in the Baltic Sea region**
- **Policy brief "Towards sustainable solutions for beach wrack treatment"**

With the help of this information, we hope that you – coastal authorities, enterprises, researchers – are inspired to adopt beach wrack treatment strategies that are environmentally sound as well as socially and economically worthwhile.

You are invited to join the "Beach Wrack Network" (*https://www.eucc-d.de/beach-wrack-network.html*) founded for the exchange between experts, practitioners, and policy makers about beach wrack issues within the Baltic Sea Region and beyond.

Jana Woelfel and Hendrik Schubert

Beach wrack-based soil production

Case study partner: Hanseatische Umwelt CAM GmbH

Location of the case study: Bad Doberan/Poel, Germany

Aim of the case study: Improve the process chain of beach wrack for soil production from a technical & management perspective. Develop and implement new business concepts for beach wrack-based soils and high value products.

Test/Research done: Knowledge in co-composting of beach wrack was gained, and new beach wrack-based soil mixtures have been developed. Process technology and methods for beach wrack recycling have been tested, and collaboration with municipalities has been deepened.

Key Activities and results

The German company Hanseatische Umwelt processes beach wrack in Mecklenburg Western Pomeranian and develops promising recycling solutions for marine biomasses. Within the CONTRA project, the production of soil improvement products has been explored from the collection of raw material at the beach site to the pre-treatment near the beach and to consequent processing on site. In addition, the collection and processing chain of high-quality eelgrass washed ashore has been tested to initiate the establishment of a supply chain for higher quality eelgrass products.

The following **collecting methods** were tested to identify their impact on the recycling pathway chosen:
Beach cleaning vehicles used to clean sandy beaches from waste are only suitable for the collection of small amounts of beach wrack. Instead, the usage of a tractor with a front loader, a pitchfork and a fixed rake in the back enables the collection of greater amounts of fresh material, especially in the splash zone. Yet, this includes the collection of large proportions of decomposing macroalgae, sand and impurities, which is inconvenient for higher-value application but can be properly used as co-composting feedstock. Most suitable as a collection method to gain individual high-quality fractions of beach wrack proves the manual collection of fresh and clean eelgrass with the help of a stone fork and plastic bags.
Results indicate that

- given the usage of the right vehicle, mechanical collection proves suitable for collecting larger amounts of mixed beach wrack.
- although less effective for beach cleaning, manual collection reduces the share of unwanted impurities, and allows the production of economically viable high-value products from e.g. eelgrass.
- a semi-machinery approach (manual pre-collection of the individual resources and subsequent cleaning by tractor) improves the economic value of manual collection.

The collection methods selected lead to different **processing options** of beach wrack:
For the processing of **clean, undamaged and long fibrous eelgrass**, an extended washing procedure with a 3-chamber washing system appears to be most appropriate. For effective drying, Hanseatische Umwelt used an algae/eelgrass drying room with electrical pre-heated circulating air.

- Best results are achieved when raw material is placed into drying boxes in a small layer, regularly turned, with pre-drying on a wooden structure. This procedure allows for higher-value application for e.g. house insulation or filling material for pillows/mattresses.

Manual collection of fresh beach wrack on the Island of Poel (2020)

Compost piles with wireless temperature probes at the Hanseatische Umwelt CAM GmbH facilities.

- **Unwashed but dried eelgrass**, collected with heavy machinery can be shredded and pelleted.
- Depending on the length of the fibres, the longer ones (>20 mm) can be used for acoustic or insulation boards. Short fibres can be used for pellets applied as organic/gardening fertiliser.

For **soil production**, composting options were examined, and the share of beach wrack to green waste material was defined as vital. Before setting up the final compost piles, beach wrack and green waste were combined. The mixture was then placed into compost boxes to start the 3–4 month composting process with regular turning of the piles every 4 weeks.

Results indicate that
- a high proportion of more than 50 % of beach wrack reduces the composting performance as it decreases the temperature in the compost piles.
- co-composting with 30 % of beach wrack (and 70 % green waste) seems to be optimal
- for optimal decomposition, the compost should be moist enough and regularly turned to bring fresh and nutrientrich material and oxygen to the core.
- regularly turning of the compost generates a rise in temperature of more than 60 °C, needed to produce quality compost and to meet the disinfecting criteria set by German biowaste regulation

Lessons Learned

+ Beach wrack constitutes a **local and sustainable resource** usable for soil mixtures and high-value products, also with comprising a **unique selling proposition** for marketing.
+ **Close cooperation of the recycling company and the municipality** is crucial and leads to better service and more sustainable solutions.
+ Combining other business areas and **diversifying the use of machinery for recycling eelgrass**, with for example washing and processing of agricultural products (e.g. herbs, salads), can make up for seasonality of available beach wrack as well as the laborious collecting method associated with it.
+ **Using beach wrack-based substrates as organic fertiliser** could reduce the application of mineral fertiliser in the Baltic coastal region and the nutrient input into the Baltic Sea.

! Tendering for beach wrack recycling services is still a common practice but makes production planning difficult. **Long-term contracts with municipalities** need to be negotiated.
! **Long-term storage of beach wrack** reduces its quality due to nutrient loss and degradation processes (methane, leachate).
! A business model that exclusively focuses on the **harvesting of eelgrass** cannot work economically and use of the production facilities needs to be diversified. Yet, a **collection which is purely mechanical** and a part of regular beach cleaning does not produce high-quality material.

Contact

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Bio-coal from beach wrack

Case study partner: KS-VTCtech GmbH

Location of the case study: Island of Rügen, Germany

Aim of the case study: Proving the concept of producing biochar from beach wrack, determining the properties of biochar made from beach wrack, and assessing the economic feasibility of a treatment plant.

Test/Research done: Collection methods have been researched and one tested, carbonization tests of various biomass samples were carried out, and biomass and biochar underwent a laboratory analysis to eventually combine the knowledge gained together in a financial analysis.

Key Activities and results

The municipality of Sellin and the municipality of Breege/Juliusruth in Germany perform beach management activities mainly during the months of May to September (tourist season). Together with KS-VTCtech GmbH, the study examined, starting from the collection of the beach wrack to its processing at a treatment plant to the final product, whether and under which circumstances an economically feasible recycling process using VTC ("vapo-thermal carbonization") could be established to produce biochar from beach wrack.
As to the **collection of beach wrack**, the study relied on analysing existing methods with vehicles also used in construction and agriculture. A cleaning trial with an amphibious vehicle, equipped with various attachments for collection, was carried out. Findings are that

- although specially designed machines would be required for adequate beach cleaning and beach wrack collection, the **usage of agricultural machines appears to be feasible** in order to diversify usage and mitigate costs.
- an **amphibious vehicle does not perform better** regarding cleaning quality, the cleaned area per hour and the contamination of the beach wrack than e.g. a wheel loader, and moreover, its usage may be **prohibited** in certain areas.

For **beach wrack treatment,** the **VTC process** applied is a thermo-chemical process, in which the natural formation of coal is reproduced within a few hours by using high pressure and heat. Along with an excess amount of water, the sample was filled into the reactor developed by KS-VTCtech GmbH and was then heated up to 220 °C for 3 hours. After treatment, the steam was released, and the cooled sample sent to the laboratory for analysis.
Results indicate that

- during the VTC process, the **relative proportion of carbon** in the biomass increases.
- the **quality of biochar** can be mildly influenced by the reaction time but is mainly dependant on the input biomass.
- the **calorific value of the product** (biochar) is harmed by a high ash content resulting from an initially high **ash content** in the biomass.
- **inert components** of the biomass have no influence on the carbonization reaction. Therefore, the biomass does not have to be pre-treated or cleaned prior carbonization.
- the treated biomass should contain **the highest possible proportion of organic dry matter** before the carbonization process.
- whether the biomass was previously dried, or stored more extendedly, produced **no systematic differences** in the properties of the biochar.

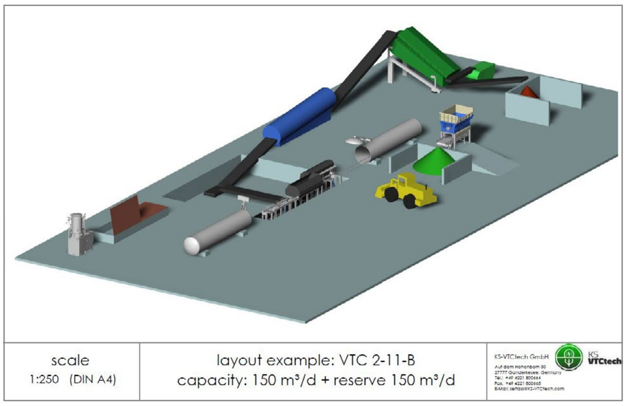
Subsequently, different **samples of marine biomass and land-based biomass** have been analysed regarding their **calorific value** and their **ash content.**

The analysis showed that

- as to the calorific value, there is no significant difference between marine biomass (beach wrack, seagrass, algae, etc.) and land-based biomass (garden waste, wood, organic waste, etc.).
- results show a **comparatively high ash content** in the samples of marine origin. Exceptions are the samples made from reeds, as they can be harvested in quite a clean manner.

Economic feasibility was researched and investigated using different parameters (composition of the material, input-material stream, reactor volume, treatments per day, etc.) as well as including investment costs and the applicable legislative framework for analysis:

- The **Law on a national certificate trading for fuel emissions** opens up the market for **alternative solid fuels**.



Layout example of a VTC treatment plant (VTC 2-11-8) with a capacity of 150 m^3/day (reserve 150 m^3/day).

- A treatment plant construction and operation for **beach wrack treatment only** would not be economically viable, because of the relatively small amount of beach wrack and its unreliable emergence.

Lessons Learned

+ A profitability calculation along with the experience from a developed example of a production plant, underlines the possibility of an **ecologically and economically safe plant construction and operation**.
+ Biochar from marine biomass profits from an increased **marketability**. The demand for alternative solid fuels, such as biochar, should increase significantly since carbon-neutral biochar is suitable for substituting fossil coal in co- or mono-combustion systems.
+ Since **biochar** is made from "fresh" biomass, it can be considered a **carbon-neutral fuel** compared to fossil coal.
+ Marine biomass (and thus also beach wrack) is **just as suited for the production of biochar** using the VTC process as land-based biomass.

! Rentability of a production plant was calculated under consideration of the **German national carbon emissions trading law**. A calculation based on the localities legal specifics is hence considered necessary for proper evaluation.

! A VTC system to be created **for the treatment of beach wrack only** would be too expensive both to build and operate in an economically feasible way, therefore, other (land-based) biomass like wood, green waste, etc. should be considered for co-treatment.

! Biomass should be stored in a way that prevents **composting as well as fermentation reactions since this would lead** to lower organic matter content and therefore a lower calorific value in the biochar.

! **The material suitability** of beach wrack as a raw material for the production of biochar being a carbon-neutral substitute for fossil fuels **has been proven**, but with the **harvesting technology** currently used, the collected material often contains a high proportion of sand, clamshells, etc., which does not influence the VTC reaction but **harms the quality of the biochar** produced.

Contact

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Beach wrack as compost to mitigate methane emissions

Case study partner: Køge Municipality. Collaboration with University of Southern Denmark and Hanseatische Umwelt CAM GmbH

Location of the case study: Køge Bay, Denmark

Aim of the case study: Test if compost made from beach wrack can be used to mitigate methane emissions from a landfill.

Test/Research done: A biocover made from compost was installed at the Tangmoseskoven landfill, Denmark, and methane mitigation was measured. Beach wrack compost was tested in a laboratory for compliance with standards for use in a biocover.

Key Activities and results

Køge Municipality in Denmark manages two local beaches mainly from May to September. This study examined whether beach wrack compost could be used as a resource at Tangmoseskoven, a discontinued landfill in Køge located close to the beach, to mitigate methane emissions from the buried waste.

Together with Hanseatische Umwelt CAM GmbH and Køge Municipality, **three samples of beach wrack compost** were tested according to the **standard protocol for the use of compost in a biocover** developed by the Danish Environmental Protection Agency. A compost must fulfil **all criteria** listed to be accepted for use in a biocover and ensure the emissions reduction effect. Nonetheless, accepted methane oxidation rates are most significant for evaluating the ability of compost to convert methane from landfill waste.

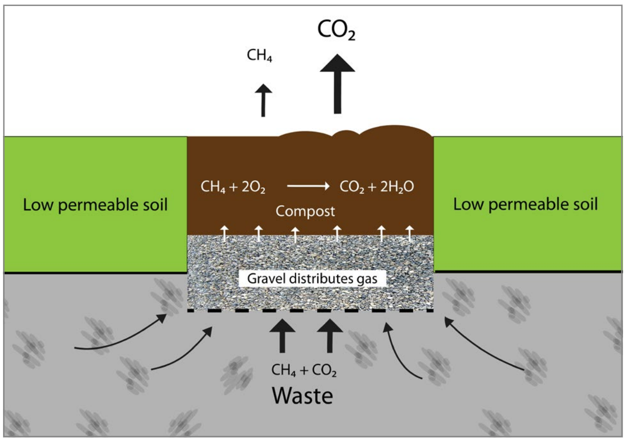
Sample 1 contained a share of **30 % of beach wrack and 70% green cut material/green waste**.
Sample 2 contained **100 % green cut/green waste**.
Sample 3 consisted of **33 % green cut/green waste, 33 % beach wrack and 33 % horse manure**.

The results show that
Sample 1 and sample 2 did not meet the criteria for methane oxidation rate and respiration rate:

- **Sample 1** only met **1 out of the 8 quality criteria** for use in biocover, possibly due to the low level of organic matter. The sample contained a **high percentage of sand** (50 %) coming from natural processes at the shore as well as the harvesting procedure which adds sand to the beach wrack material. Additionally, the **degradation** was already at an advanced stage, impacting the results.
- **Sample 2** fulfilled **5 out of the 8 quality criteria** for use in biocover. However, its values of methane oxidation rate and respiration rate were not acceptable.

Sample 3 from Køge Municipality met **4 out of the 8 of the quality criteria** for use in biocover.

- Although sample 3 did not meet all quality criteria, it had **accepted values of methane oxidation rate and respiration rate**. However, the compost from sample 3 **emitted some methane**. Active compost may stimulate methane-oxidizing bacteria, thus furthering methane conversion but this must not exceed the total methane oxidation rate, resulting in total methane emissions.



Biocover "window" system (after [Kjeldsen & Scheutz, 2014]). A biocover consists of a layer of compost and a gas dispersal layer usually made from gravel. Methane gas is dispersed to the compost layer where methane-oxidizing bacteria convert it into CO2. CO2 is a greenhouse gas 25 times less potent than methane.

Construction of the biocover at Tangmoseskoven in 2020.

A biocover using standard compost made from green-cut waste was established at Tangmoseskoven. This compost fulfilled all criteria for use in a biocover. Measurements showed that the plugging of boreholes in the landfill and the establishment of the biocover on hotspots emitting methane reduced methane emissions **from 17.2 kg methane/hour down to 2.2 kg methane/hour**. The biocover alone is estimated to be responsible for 60% of this emissions reduction.

Lessons Learned

+ A biocover made from compost that fulfils the criteria can effectively reduce methane emissions from landfills
+ Recycling beach wrack into compost may be **particularly relevant where beach wrack is mixed** and cannot be separated into macroalage and eelgrass fractions for direct reuse.
+ Compost made using **30 % beach wrack can be suitable for use in a biocover** as it can have an acceptable methane-oxidation rate. Yet, **more research is needed** to understand its precise effect on methane-oxidizing bacteria and the proposed quality criteria.
+ **Cooperation with waste management companies** with access to more organic material that can be co-composted with beach wrack is beneficial.
+ **Methods and machinery for collecting beach wrack used by municipalities are not optimal** for later beach wrack recycling. A **closer cooperation with local actors**, such as farmers with land near the sea, private beach cleaning companies, or private-public waste management companies, who have available machinery and space to produce beach wrack compost, may prove advantageous.

! Beach wrack must be **mixed with a large portion of other organic matter** (70 %), such as cuttings from gardens or parks to ensure that it will compost. The suitability of beach wrack compost may depend on the composting process, organic material and the specific composition of the beach wrack. **The share of sand is a critical factor**.

! **Planning for the collection of beach wrack** and green waste simultaneously, as well as the subsequent **composting**, can be challenging due to **variations and seasonal limitations** on the availability of these materials.

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Beach wrack for dune restoration measures

Case study partner: Atlantic Branch of P. P. Shirshov Institute of Oceanology of Russian Academy of Sciences (ABIORAS) in cooperation with the National Park "Curonian Spit" and coastal authority "BALTBEREGOZASTITA".

Location of the case study: Curonian and Vistula spits, Kaliningrad Oblast, Russia

Aim of the case study: Test if beach wrack can be used for coastal protection measures (for the planting of greenery and sand retention in wooden cells).

Test/Research done: The experiments were focused on the use of beach wrack-based compost in coastal erosion protection measures: (a) to promote plant growth and root stability for artificially planted greenery on the backside of the coastal dune, and (b) by using the beach wrack as initial filler for the wooden structures on the seaward side of the dune to facilitate a natural accumulation of beach sand and rooting of sand-holding grasses.

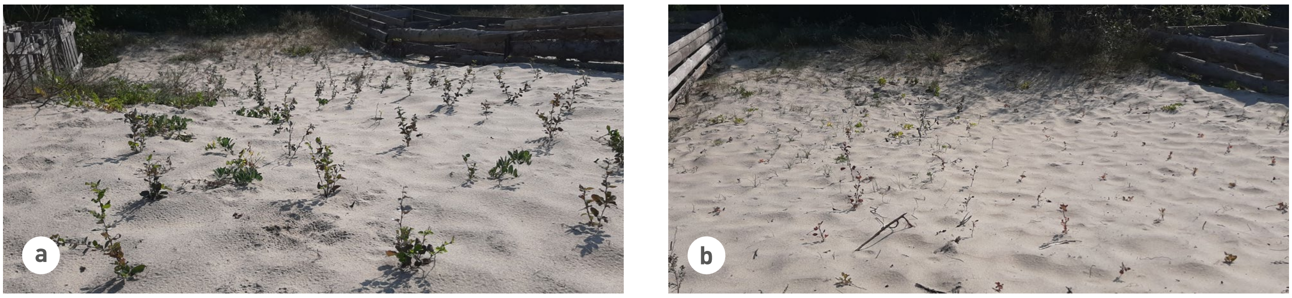
The case study examined if beach wrack-based compost could be used for dune restoration purposes. So far, beach wrack has only been removed but not processed in preparation of the touristic season in this region.

For an **efficient and cost-effective harvesting**, webcam observation of the seashore proved most feasible to coordinate the beach wrack harvesting activities, as seasonality and availability of beach wrack mostly define the suitability of the restoring methods tested. Collection of the beach wrack was done manually with no further separation of impurities for both options tested.

As for the use of **beach wrack for the planting of greenery**, organic fertilizer from beach wrack was obtained by **composting**. The experimental composting site was a square wooden container (2×2×1 m) placed on low brackets to improve aeration. Beach wrack was placed in the compost container's central part, covered with hay, without any tamping. The **composting process lasted for 6 months** and no additional irrigation was done. The surrounding temperature was 0–+7 °C in winter, and aeration of the compost mass was carried out by stirring it within the first month after starting the process. The planting of greenery was carried out at the experimental and representative sites to identify the differences' significance. Beach wrack compost **was applied at a depth of 20–30 cm directly beneath the seedlings' roots**.

Results were that

- before application beach wrack **should be composted for 4–6 months** and the compost mass should be **stirred 3 times per preparation period** for aeration.
- **high sand content** in beach wrack is not a problem when used in dunes.
- due to the **harsh habitat conditions, berberis vulgaris** (as a native species) proved most feasible for planting as it is tolerant of low soil humidity and low temperature.
- **plant yearlings** with a stem length of more than 10–15 cm should be used for planting.
- the **survival rate of the plants** was 83 % at the experimental site and 88 % at the verification site; the plants grew in height compared to the initial size by 52 % ±3.1 % and 25 % ±3.0 % respectively.



Results of the planting of the seedlings at (a) experimental and (b) verification sites in September 2020 (one vegetation season cultivation). Photo: J. Gorbunova.

— the **amount of compost applied** should depend on the plant's needs for 1–2 years. In the case of berberis vulgaris yearlings the range was between 0.6–0.9 l of compost per seedling.

A **cost calculation of planting the greenery** (with and without compost) took into account: cultivation of planting material (seedlings of Berberis vulgaris); planting and cultivating berberis vulgaris yearlings (within one vegetation season); beach wrack composting technology:

— The **costs per 100 plants were 35 person-hours** in the case of beach wrack compost application, and **11 person-hours** without it.
— The **growing of seedlings with compost** costs about 3.5 times more in the first year.

Construction of the wooden cells (1.5 × 1.5 m) and the initiating the sand accumulation is a traditional way to restore the wind-blown gaps in the foredune wall. The **application of beach wrack as a preliminary filler for cells** (30 pails per cell) was investigated:

— Filling the cells with beach wrack **did not influence final sand accumulation** in the cell. It only helped at the initial stage. After several windy periods, all cells were nearly equally filled with sand.
— Beach wrack itself is **not a suitable substrate for grass growing**. The grass (planted with seeds) grew only in the cells, which were partly filled with ordinary humus together with beach wrack.
— a **two-row (or more) cell construction** showed the best results for sand accumulation.

Lessons Learned

+ Beach wrack has **the capability of being an additional improver** in ongoing shore consolidation activities and offers the opportunity to **make use of amounts of beach wrack** that is collected anyway to clean beaches for touristic purposes.
+ The **use of beach wrack for dune greenery is effective** and its use is **preferable** compared to other materials, as it is not an extrinsic agent for the coastal ecosystems.
+ The **viability of plants** grown with compost is much higher than without and beach wrack compost ensured nearly **2 times faster plant growth**.
! The **cost of growing plants with beach wrack** compost is about **3.5 times higher** than without and the **survival rate of seedlings** grown with and without beach wrack compost was practically equal after one vegetation season.
! **Sorting out macro- and part of mesoplastic** during the beach wrack and compost processing is desirable at the beginning and the end of the technological process. The microplastic is buried in the ground and cut-off from high levels of the food web.
! Beach wrack is **suitable as initial filler for wooden structures** only when seeds of sand-holding grasses are inserted.

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Beach wrack treatment in reed bed systems (RBS)

Case study partner: Department of Water and Wastewater Technology, Faculty of Civil and Environmental Engineering, Gdańsk University of Technology

Location of the case study: Swarzewo, Poland

Aim of the case study: Transform beach wrack into soil conditioner or fertiliser using a natural based solution – reed bed system (RBS).

Test/Research done: Investigating the quality of raw beach wrack, quality of material treated in the reed bed system as well as the quality of reject water from the system.

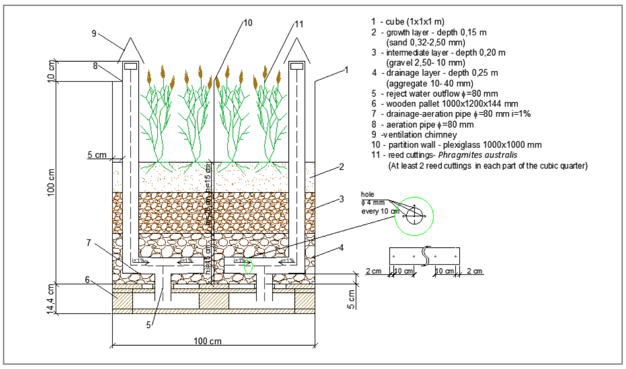
To transform beach wrack from nuisance to a resource, the Gdańsk University of Technology, Poland, has tested the possibility of a reed bed system (RBS) to obtain fertiliser or soil conditioner from beach wrack as a final product. The RBSs are commonly known for the treatment of different kinds of sewage sludge. The average system works 8–12 years, but it can be extended up to 15 years. The operation time consists of start-up time, full operation time and system emptying periods. The basic principle of reed systems operation is based on the use of processes naturally occurring in wetland ecosystems in controlled environmental conditions.

A **model facility** was built at the Wastewater Treatment Plant in Swarzewo in autumn 2019. The beach wrack material was collected on the beach in Rzucewo and cyclically fed into individual parts of the reed bed. Two reed bed systems were built, divided into 4 parts each. Each part was fed with different loads of beach wrack or mix of beach wrack with compost. Material charging was done manually. The system works in an altering cycle. There are two phases of work: (i) irrigation – the supply of raw material and (ii) rest – break from feeding the system with beach wreck. There are no precise guidelines for the exact timespan between charges. The intervals between subsequent irrigations depend on the efficiency of the bed, atmospheric conditions, the age of beach wrack, dry matter concentration in beach wrack and thickness of the layers of accumulated material. More extended periods between irrigations may result in better dewatering and stabilisation efficiency.

First, the supply with beach wrack took place in October 2019. Then, the pilot system was resting for 5 months. In April 2020, the research team began to regularly add beach wrack material into the RBS's pilot plant. In 2020 there were five monthly research campaigns. During four of them, the bed's quarters were supplied in the same amounts and mixing proportions of discharged material: (i) 10 l algae; (ii) 15 l algae; (iii) 10 l algae mixed with 10 l compost; (iv) 5 l algae mixed with 5l compost. From August 2020, two more quarters were additionally supplied: (v) 5 l shredded algae; (vi) 5 l shredded algae mixed with 5 l compost. Each month, the beach wrack collected for research was at different decomposition stages, reflecting its basic parameters.

The bed material was dewatered and subjected to a stabilisation process, which is indicated by a decrease in the content of organic matter. Content of nitrogen in analysed material was from 6.5 to 27.9 g/kg d.m. (for beach wrack) and from 11.9 to 28.4 g/kg d.m. (for beach wrack mixed with compost). While in case of phosphorus its content ranged between 4.8 to 15.3 (for beach wrack) and 15.6 to 30.6 g/kg d.m. (for beach wrack mixed with compost). For comparison, the content of above-mentioned nutrients in beach wrack before discharging into RBS was between10.1 to 30.5 g/kg d.m. for nitrogen

Constructed pilot plant of RBS at WWTP in Swarzewo: two cubic pilot plants RBS (August 2020), photo: A. Kupczyk



Scheme of pilot reed system based on cubic modules [A. Kupczyk's study]

and from 8.0 to 24.8 g/kg d.m. for phosphorus. The lowest content of nutrients was found in April and the highest in period from July to September. The obtained content of nutrients is similar to those in sewage sludge, thus the material from the RBS can be considered as a fertilizer or a soil conditioner.
In the case of **reject water**, it was not easy to establish a repeatable test scenario. Every month a different amount of reject water from the reed system was collected.

— The difference of reject water depends on the vegetative conditions of the reed and weather conditions occurring in that specific month. The quality of reject water is rather good. Considering the small amount of reject water, the load of pollutants is very low and does not negative impact on environment. Very important is low concentration of ammonium nitrogen which indicates that oxygen processes are taking place in the analysed RBS.

Lessons Learned

\+ **RBS solutions** fit in assumptions of a **circular economy** and change beach wrack into a **resource** (soil conditioner or fertiliser). This gives the possibility of reintroducing nutrients into the matter cycle and allows reusing these compounds in a place where they are desirable.

\+ This solution has a **low carbon and water footprint**. Due to the mineralisation process, the production of greenhouse gases is inevitable. Still, a well working system **decreases the amount of methane** produced to a **minimum** and supports methane oxidation by aerobic methanotrophic bacteria.

\+ The RBS is an **environmentally friendly solution**. The system's work is based on natural processes occurring in wetlands, and it takes place without the use of additional chemicals or energy supply.

\+ Beach wrack material is a **source of nutrients for reed and positively affects its growth**, indicating **good fertilising** properties.

\+ The system **does not require large financial outlays** due to the simple construction setup and low operating costs.

! The deposit start-up period of a RBS can take about 2 years.

! The beach wrack material properties are usually unknown, making it difficult to determine the **appropriate dose and frequency of charges**.

! Depending on the amount of beach wrack material to be processed, an RBS may require **significant space** which entails the need of purchasing or owning land for the construction site of the RBS.

! Fresh beach wrack contains considerably high volumes of (micro)plastic and other **undesired waste material having to be removed before use**.

! Before implementation, it should be examined whether the produced soil conditioner's or fertiliser's **properties meet legal requirements**.

Contact

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