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Beach wrack of the Baltic Sea – Conversion of a nuisance to a resource and asset (EU-INTERREG project)

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Umschlagfotos: Beach wrack at beaches of Warnemünde Germany (© Jane Hofmann)

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Foreword

Meeting public expectations of 'clean' recreational beaches is an ongoing challenge for coastal communities. Current management of beach wrack (cf. introduction) is not straightforward and needs a wide-ranging concept that crosses municipal, regional and national boundaries. This special volume of the Rostocker Meeresbiologischen Beiträge aims to provide an overview of the results of the EU Interreg project CONTRA "**CO**nversion of a **N**uisance **T**o a **R**esource and **A**sset" (2019–2021), funded under the Baltic Sea Region Programme.

Over the course of two years, CONTRA has gathered the knowledge and built the capacity to exploit the potential of using beach wrack for the entire Baltic Sea Region. The environmental, social and economic aspects of different collection and reuse options were investigated and evaluated at national and international levels in five sub-projects and seven case studies. This volume thus provides a comprehensive assessment of all perspectives related to beach wrack removal, and ideas for sustainable options for pollution and nutrient remediation have been put forward. 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.

The results of the work are presented in four thematically in-depth analyses, which are divided into the corresponding four chapters of this special volume:


Socioeconomics


Ecology


Technology


Business

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

- **"Tool kit"** (covering practical aspects of beach wrack management and provides guidance for local and regional decisions makers)
- **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.

Furthermore, 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.

Rostock, September 2021

Jana Wölfel *Hendrik Schubert*

(Lead Partner on behalf of the CONTRA consortium)

Introduction

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: 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.

"As long as we have to compete with 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). 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. 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. Hence, the challenge of beach wrack removal is to find a balance between public demand for 'clean' beaches, environmental protection and the economy.

CONTRA aimed to change how coastal municipalities see and deal with beach wrack and help convert this nuisance into a resource and asset. We hope that doors will be open to future cross-border collaboration a little wider, with the ultimate aim of delivering a 'win-win-win' situation – namely, improvements in coastal water quality, clean & healthy beaches and blue growth opportunities for the Baltic Sea Region.

Socioeconomic impacts of beach wrack management

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Large beach wrack landing on German Baltic Sea beach (© J. Hofmann)

About the author

This report has been produced by EUCC – The Coastal Union Germany (EUCC-D) as an output of the CONTRA project. EUCC-D supports Integrated Coastal Zone Management (ICZM) by bridging the communication gap between research, policy and practice, and by facilitating stakeholder engagement. We offer advice, training, and development support to local authorities, as well as public outreach and awareness raising on socio-economic issues affecting the coast, sea and catchment areas of European waters. Within our profile area, the triangle of coastal tourism, environment, and sustainable development, EUCC-D works with coastal communities and creates partnerships and projects at the regional, national and international level.

EUCC-D's role in the CONTRA project

The CONTRA project was structured into four main work packages, each covering the beach wrack challenge from separate perspectives. EUCC-D's main task was to lead the work on socio-economics within the field of beach wrack management, with special attention on the tourism sector and the demand for beach wrack removal. During the project, EUCC-D led an international public survey, the establishment of beach wrack working groups in each partner country and open interviews with beach managers and local experts. The aim of the working groups was to share knowledge and synchronise efforts towards improved understanding and management of beach wrack at the CONTRA case study sites. Local research activities were done in a collaborative fashion with help from designated national Working Group Coordinators. The results of these activities are a fundamental part of the research which this report builds on.

How to read this report

The aim of this baseline report is to offer insights, and knowledge about the socio-economic components relating to beach wrack and its management. It targets policy makers, municipalities, tourism service providers, and researchers who wish to explore ways of balancing the environmental, social and economic impacts of beach wrack practices. Besides the introduction and conclusion, this report's body is divided into 7 sections. Approximating the driver-pressure-state change-impact-response (DPSIR) framework, the main body discusses each of the DPSIR elements relevant for socioeconomics of beach wrack management in the BSR in a sequential fashion. The framework is described in more detail in Section 2. As this is a baseline report, it consists of roughly an even mix of two sources of data. On one hand, it summarizes existing data available in previously published scientific literature on the topic. On the other hand, it introduces own data from several of CONTRA's own questionnaires, including a survey of the general public and a questionnaire issued to relevant beach managers.

Summary

This baseline report tackles the previously unexplored topic of the socioeconomic aspects of beach wrack management in the Baltic Sea Region. While it serves as a general overview and synthesizes the findings of multiple relevant academic works, it also introduces new information from the project CONTRA (2019–2021) and its seven case studies in the region, both those specifically relevant to the locales and generalized findings. The report focuses on managed tourist resort beaches. It starts with the history of beach wrack and beach wrack management before moving on to the main drivers of beach cleaning and beach wrack removal: tourism and recreation. It then looks at various aspects of concern expressed by relevant stakeholders, including public opinion, health and safety, coastal landscape and conservation, knowledge and development. It finally provides an overview of findings to be applied at each stage of beach wrack management and ends with a short conclusion.

The main takeaway of the report is that both management considerations and research work regarding beach wrack management in the region are in their infancy. While multiple socioeconomic and environmental factors are at play at every case site, they rarely appear as a consideration. In contrast, financial aspects are commonly measured or approximated using indicators and factored in to the decision making that goes into beach management. The sheer complexity of the factors at play makes balancing stakeholder interests very difficult even in the short- and mid-term. In the long-term, structural considerations such as the impact of climate change and shifting tourism flows make providing recommendations a Sisyphean task. While the report is an important first step in establishing and increasing awareness of these factors, further research is required to develop concrete and streamlined guidelines on a local level that beach managers can refer to while considering all relevant specificities of their beaches.



1 Introduction

In the Baltic Sea Region (BSR), many communities have an intricate social and economic connection to their coasts. The coasts and beaches have a strong social, historical, and economic value to local residents (HELCOM 2017). While thriving Hanseatic League trade boosted the growth of vibrant commercial port cities, the forces of nature sculpted beautiful and sometimes dramatic landscapes, offering themselves forward as prime tourist destinations. Over the years, the prime locations gifted with natural coastal beauty emerged as best examples of what Baltic Sea tourism has to offer. Tourism revenue has become a primary source of income for most of these communities (Haller et al. 2011).

For such communities, one very challenging issue can be the organic material that gets washed up with wind and waves, namely beach wrack. Some beach wrack 'hotspot' areas, like the Island of Poel in Germany, experience landings of up to 1000 metric tons of beach wrack per month (CONTRA – Management Summary Report 2021) along main tourist beaches. Since competition between beach tourism destinations is strong and there is a real threat of income loss if beaches fail to meet public expectations, local authorities are under great pressure to remove beach wrack. However, this comes at a great financial cost. Recent estimates to collect, remove and dispose of beach wrack put the cost for municipalities at between 20 €–40 € per meter of beach length (CONTRA – Management Summary Report 2021). According to unstructured interviews we had with beach managers in 2019, municipalities generally treat beach wrack as an organic waste. Thus, they almost never generate any money back from processing and use. The main driving factor behind beach wrack removal is thus the economic value of cleaned sandy beaches for the tourism sector and the local economies (CONTRA – Beach wrack in a business environment 2021). The explanation beach managers provided for this is that the general public associates beach-wrack-free beaches with high-quality tourist facilities and services.

Beach cleaning operations can, however, inadvertently alter the coastal landscape and the beach

Figure 1 Birds feeding amongst rotting beach wrack on tourist beach (© EUCC-D)



ecosystem, with long-term social and economic consequences (CONTRA-report Möller et al. 2021 about ecological aspects). Altering the provision of ecosystem services, including biodiversity and coastal protection, may over the long-term result in decreased attractiveness for the beach and, in turn, negatively affect tourism and recreational activities. Financial impacts of beach wrack removal include the direct cleaning costs and the loss of tourist revenue in affected coastal areas (CONTRA-report Almqvist et al. 2021 about beach wrack in a business environment). Negative social impacts, such as reduced benefits from access to coastal environments and well-being losses from living in a perceived degraded environment, may also be present. These may affect the sense of identity and community, reduce opportunities for recreational activities, and potentially pose health risks to coastal visitors.

The role of beach wrack in the interplay of society, environment, and the economy in the BSR has thus far been scarcely researched. Existing studies have analysed various ecological aspects of beach wrack, but have rarely specifically linked them to society. The few attempts rarely relied on own social and economic data (see Hammann and Zimmer 2014; Filipkowska et al. 2008; Mossbauer et al. 2012). When assessing socio-economic impacts of beach wrack, it is important to recognise that each site is unique and that factors to consider include beach type, morphology, public infrastructure and services, cultural identity, coastal landscape, and local flora. While the impacts of beach wrack and its management are complex, we could not find studies that have specifically addressed them. This is true not only for the BSR, but for Europe and the rest of the world as well.

This report aims to identify and describe the key socio-economic components of beach wrack management in the BSR and to highlight the human dimension of beach wrack management on managed tourist resort beaches. It introduces own data in the form of several questionnaires put out to relevant stakeholders, including the general public, beach managers, and beach wrack experts from the region. Working groups based in each participating country organized unstructured interviews with these relevant stakeholders as well. At the start, the history of beach wrack and beach wrack management is briefly presented. Next, the main drivers of beach cleaning and beach wrack removal, tourism and recreation, are analysed. We then look at various aspects of concern expressed by relevant stakeholders, including public opinion, health and safety, coastal landscape and conservation, and knowledge and development. Lastly, this report provides an overview of findings, best practices and lessons learned at each stage of beach wrack management.

2 Beach Wrack of the Baltic Sea Region: The Basics

Why does beach wrack deserve to be considered when managing a tourist resort beach? A common public view is that it is a conglomerate of natural and manmade material that washes up on the beach every now and then. It is thought to have little or no use to society, essentially being a waste product and a nuisance that should be removed. In practice, beach wrack is a complex organic material generating a number of eco-system services (CONTRA-report Möller et al. 2021 about ecological aspects). In the BSR, it is primarily made up of torn off seagrass, macro-algae (brown, green and red species), shells and even dead animals. Its content varies depending on the location, time of year, and other environmental factors (Chubarenko et al. 2020). On one hand, beach wrack is a key part of the beach ecosystem. On the other hand, the public survey (Hofmann et al. in preparation) has shown that its presence can be problematic and have undesired effects for beach users. What it consists of and how it is collected determines its usability as a resource, which can be very high or even none (CONTRA-report Chubarenko et al. 2021 – Case studies for innovative solutions 2021). Determining if it is problematic and how to remove and process it comes down to decisions made by beach managers and the local public authority or landowner. In the long term, every beach wrack management policy has an impact on how a given beach's ecosystem evolves. To set the scene, let us first look at the history of beach wrack perception and treatment in the BSR.

2.1 A Centuries-old Traditional Resource

Beach wrack has featured in the daily lives of Baltic Sea coastal communities for generations. Prior to 19th century industrialization, it was largely seen as a versatile resource. Various traditional uses



Figure 2 Fresh seagrass covering the foreshore (© J.Hofmann)

for beach wrack include: mattress filling, livestock fodder and bedding, souvenirs, fertilizer, soil improvement, insulation material in construction and bedding, tobacco supplement, food, and medicine (Heywood 1996; Heimatmuseum Warnemünde 2020). There is no evidence of a systematic treatment or management practice beyond removing what was needed for the specific application. The randomness of the location, time and composition of beach wrack likely prevented a more systematic exploitation of the material. Despite its unpredictability, its unique properties made pure seagrass that was washed ashore a valued resource. Its qualities include durability, mould and fire resistance, effective insulative properties, and non-attractiveness to vermin and pests (Posidonia-Dämmstoffe 2011). At least since the early 18th century up until around 1930, BSR coastal communities saw great value in beach wrack as a resource. Unfortunately, seagrass meadows were decimated by a wasting disease that emerged in the 1930s and peaked in the 1970s and 80s (de los Santos et al. 2019). At around the same time, in the Baltic Sea, the level of nutrients, including nitrogen and phosphorus (Larsson et al. 1985), as well as heavy metals, progressively increased (Bernes 2005). We could thus infer that water quality in the Baltic deteriorated. During this time, societies moved to synthetic and man-made building and filling materials and beach wrack use declined. In turn, this contributed to a wide-scale loss of the skills and know-how of sustainably utilizing beach wrack.



Figure 3 Historic Danish seagrass roof (© Læsø Museum, Denmark)

2.2 Becoming an Undesirable Object

At some point in the late 19th century, the centuries-old tradition of coexisting with beach wrack

Traditional applications of beach wrack across the BSR

Denmark (Læsø Museum n.d.)
Evidence of the strong Danish culture around seagrass use can still be found there today. On the island of Læsø, the tradition of seagrass roofing can be traced back about 800 years. There are still about 20 houses, with traditional seagrass roofs dating back over 300 years, standing as monuments to a time when communities relied on local resources. In the 1930s, eelgrass near Læsø died out due to a fungal infection (Læsø Museum n. d). Recently Læsø roofs have been restored and an effort has been made to re-educate roofers in the roofing technique.
There are also remnants of old seagrass boundary walls on the Danish islands. In the early 18th century, eelgrass was used in Denmark and Sweden, to build dikes and dams to protect low-lying coastal areas against storm floods.

Germany
Fishermen working in the Wismar area of northern Germany, supplemented their daily income by selling seagrass to local residents and it was also here where a number of seagrass processing and upholstery companies emerged. Records show that the use of seagrass even extended to the filling of cushions in ships and trains.

Sweden
Due to the availability of nutritious beach wrack that they could easily collect, farmers established agricultural "beach" fields near the coastline and fertilized them with beach wrack. Beach wrack was also used to stabilize sand on the beach and prevent sandstorms.



Figure 4 Mechanical beach wrack collection (© Hanseatische Umwelt CAM GmbH)

and treating it as a resource to be used in everyday life slowly broke down. Industrialization, the advent of railways and the increasing popularity of tourism likely helped influence a shift in the perception of beach wrack (Bal and Czalczynska-Podolska, 2020). New marketing vehicles that relayed an image of the newly hip beach destinations, such as postcards, did not market beaches full of beach wrack, but "pristine" ones free of it. City dwellers now visiting these destinations were less likely to be as aware of the value of beach wrack as the local residents. The composition of beach wrack itself also likely started to shift. around that time (Chubarenko et al. 2020). It is not clear how far back organized beach cleaning goes, but it is highly unlikely that it began before tourists generated the demand and funding for it.

In the BSR, the beginnings of beach tourism can be traced to the early 1800s. The large-scale demand for beaches free from litter and other items washed ashore, including beach wrack, probably only appeared once the advent of railways in the mid-19th century brought large numbers of far-flung visitors to beach resorts for the first time (Bal and Czalczynska-Podolska, 2020; Heimatmuseum Warnemünde 2020). Of course, not all beach tourist sites in the BSR will have enjoyed a direct rail link with the large cities. Less accessible locations only got more tourists with the advent of the automobile in the 20th century (ibid). The increasingly negative perception of beach wrack will have been accompanied by the development of ever larger and more sophisticated machinery used to remove it. At first, beach wrack was only collected by hand, possibly with the help of simple tools like rakes and pitchforks. Sometime in the 20th century, agricultural tractors with dedicated attachments started becoming more common, including among our respondents. However, the large-scale mechanical beach cleaning taking place today only goes back a few decades. For example, a notable early adopter of purpose made beach cleaning vehicles was the 1996 Atlanta Summer Olympics (Sack 1996).

2.3 Newfound Beach Management Consideration

Describing how beach wrack serves the local environment, society and the economy can be done by assessing its contribution to ecosystem services. Ecosystem services can be broadly defined as "the benefits people obtain from ecosystems" (MEA 2006). Some services provided to people by sandy beaches will be direct and easily perceptible, such as beaches being an aesthetically pleasing recreation space with good air quality. In contrast, they are also likely to be less obvious and have more indirect benefits. An example of this is the services provided by beach wrack. One service is that it is used by endemic birds for nesting, shelter and food (McCulloch 1996), helping to keep the local food chain in balance. Other benefits of beach wrack include mitigating climate change effects and reducing sand erosion (GSA 2017). While these ecosystem services have an economic impact, especially in the long-term, they are notoriously difficult to quantify and thus to incorporate in policy (Gómez-Baggethun and Ruiz-Pérez 2011). More information about ecosystem services can be found in CONTRA-report by Möller et al. 2021.

On tourist resort beaches, beach cleaning, which includes the removal of beach wrack (sometimes called "beach grooming"), alters the ecosystem services of the beach. The relative importance of the various ecosystem services provided by sandy beaches in the BSR changes depending on whether the beach is managed or not. We define managed beaches as beaches where the following criteria is met: 1) they are used for recreational purposes, 2) there is a dominance of sandy sediments, and 3) beach wrack is removed from them on a regular basis. An illustration of the shifting relative importance can be found in CONTRA-report Möller et al. 2021. On unmanaged beaches with beach wrack, the relative importance of biodiversity and habitats, natural heritage, and knowledge systems is higher, with the overall picture being more balanced. In contrast, on managed beaches, there is

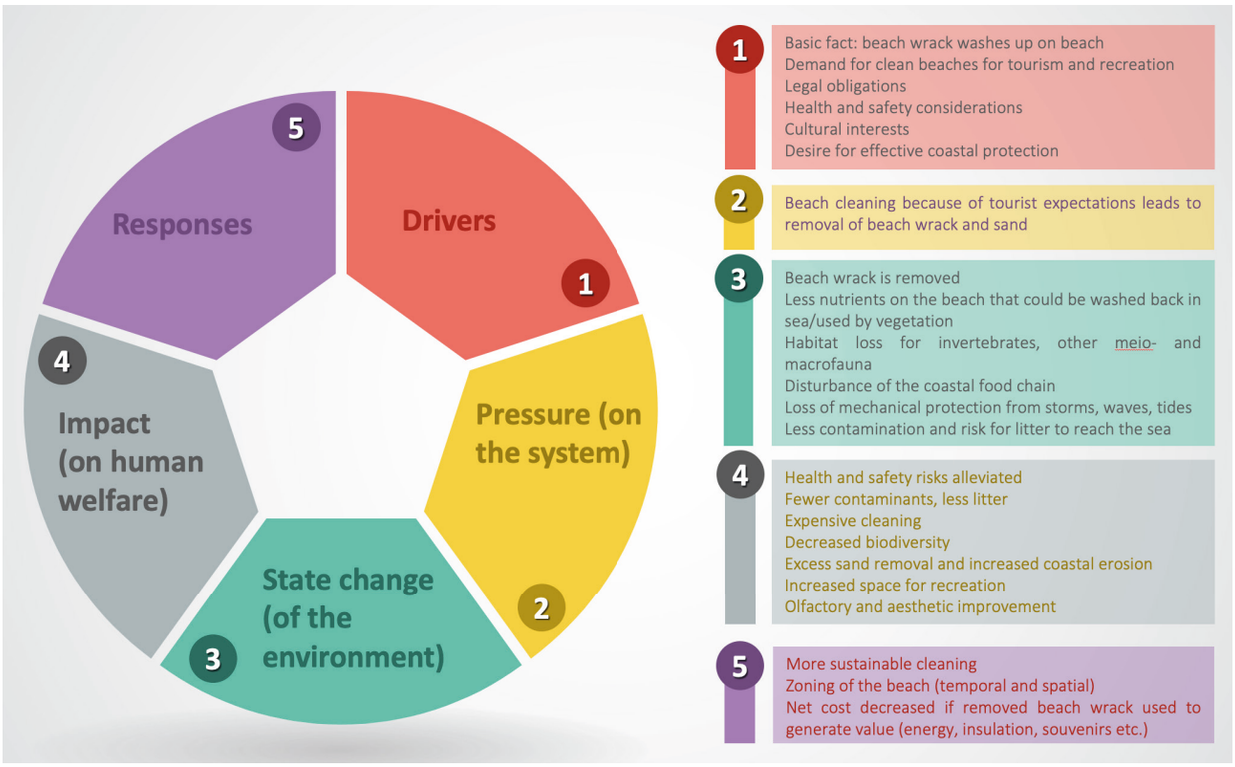


Figure 5 Illustration of beach wrack management dynamics using the DPSIR framework (© EUCC-D)

a strong bias towards a single ecosystem service: tourism-oriented recreational services (CONTRA-report Möller et al. 2021).

The following sections describe how this dynamic takes place and how it impacts the individual socioeconomic sectors and their various stakeholders. In this report, we will loosely follow the driver-pressure-state change-impact-response (DPSIR) framework to describe beach wrack management in the BSR (Elliott 2014). We illustrate the various directions managed beaches can take depending on local priorities, as well as the impact that the individual drivers of beach land use may have on the local society, economy and the environment in the short, mid- and long-term. We also present historical case studies of beaches that have adopted specific policies and the observed effect such policies have had on the beach environment. Our own data comes from a series of questionnaires with the public, local beach managers, and experts working in the field of conservation, open-ended discussions with local experts, and local meetings with working groups from each studied site. The intended outcome is that, by the end of the report, readers will have a better idea of the impact beach wrack management policies have on the beach and coastal communities and how these policies could be adjusted. But first: what is already being done to shift the public perception and political attitude towards beach wrack?

The shifting narrative surrounding beach wrack contributed into making it an example of how society gradually abandoned a naturally occuring, mostly organic raw material and moved to synthetic alternatives. The former natural materials play a key role in trying to reinvent BSR economies to become more sustainable in line with political goals set out by HELCOM (2017) and the European Commission (2014a). Beach wrack specifically offers a plethora of options in developing the blue economy, circular economy and bioeconomy. A holistic approach to beach management implying a balancing of environmental protection, social considerations, and economic development would help achieve this in the long term. If the local authorities wish to comply, they would have to employ a sustainable long-term strategy in managing their beaches – including their beach wrack. Plenty of opportunities exist to readjust the treatment of beach wrack with greater sustainability in mind. While historical use cases of beach wrack present potential for rediscovery, there are fresh possibilities for beach wrack use abound in cosmetics, pharmaceuticals, soil improvement, biogas, and coastal protection, among others. Some of these use cases are also presented in the report.

3 Tourism and Recreation

The main sources of economic value on managed beaches are tourism, recreation and associated activities (CONTRA-report Almqvist et al. 2021 about beach wrack in a business environment). The EU Commission's Blue Economy report states that coastal and maritime tourism is the largest sector in the blue economy, accounting for over 50 % of the job opportunities and 36 % of the GVA (Gross Value Added) (EC, 2019). A fact of nature is that beach wrack regularly washes up on most of managed BSR beaches surveyed in our management questionnaire. On these beaches, it is often considered as a potential nuisance to value generation (CONTRA – Management Summary Report 2021). This drives beach managers to remove it. This section analyses this economic value in more detail.

3.1 World and European Tourism: Trends and Figures

Tourism is one of the world's largest economic sectors, consistently increasing in value. UN data shows that global tourist arrivals continued to increase in 2018, maintaining a positive pattern seen since 2009. Over 9.25 trillion USD is contributed by tourism and travel to the world economy. A total of 1.46 billion arrivals were recorded in 2019; over 4.7 billion USD alone was spent on leisure travel. Europe is one of the world's most popular vacation destinations. In 2018, the wealth of European cultures, the variety of its landscapes and the quality of its tourist infrastructure have, among other reasons, attracted over a third of the world's international tourists to holiday in the EU-27 (EC 2020a). Tourism is a key economic component in many EU regions, especially in peripheral ones like the BSR. Coastal and maritime tourism typical for BSR has been identified as one of the five sectors of Blue Growth (EC 2014b). On one hand, tourist infrastructure "contributes to local and regional development, while jobs that are created or maintained can help counteract industrial or rural decline" (EC 2020a). On the other, tourism can have negative consequences. Excess demand can strain local infrastructure and hinder daily lives within local communities. Tourists harm the environment locally through noise, pollution, waste, and habitat loss; and globally through transport-related Greenhouse gas emissions (EC 2020a).



Figure 6 Busy tourist beach in Poland (© D. Szponder)

3.2 Socioeconomic Development in the Baltic Sea Region

Many BSR locations benefit from ecosystems that feature endemic marine flora, fauna, and, perhaps most importantly, wide sandy beaches. For developers and politicians, the most alluring financial prospects for their coasts lie in the tourism revenue. Unlike some other forms of tourism that require significant capital investment early on, e.g. cultural tourism, the tourist attractions of an area with sandy beaches, which "represent the primary natural capital on which seaside tourism is based", already exist (Flayou et al. 2021). Such tourism brings a strong influx of revenue spread over a wide variety of service industries such as catering, accommodation, transport, and recreational activities such as swimming, diving, sailing, and surfing. There are even purpose-built coastal resorts creating and catering to such tourist demands for sandy beaches in every BSR country. Examples include Prora (Germany), Sopot (Poland), Liepaja (Latvia), and Haapsalu (Estonia). A correspondingly high number of hotels, restaurants, cafes, night clubs and other businesses reliant on tourist revenue operate in the resort areas. In addition, unlike some types of social and cultural tourism, beach tourism appeals to international tourists. The latter contributes to the tax revenues of host country

governments through various taxes paid on their trip. Yet, as they are short-term visitors, the government does not have to spend any of their tax revenue on them through welfare, as they do with their own citizens (Orams 2003). This makes international tourists a particularly appealing source of income.

In the BSR, the beaches along the Baltic coast help their surrounding communities generate economic revenue from tourism and recreation. Beach tourism and reliant types of tourism, such as meeting, incentive, conference, or exhibition tourists, as well as recreational, medical, wildlife and eco-tourists, are a natural fit for a region rich in attractive sandy beaches but with relatively few major cities (Jędrzejczak 2004; Flayou et al. 2021). Germany, Poland and Russia were named in the UNWTO list of top 10 destination countries globally (EC 2020a). While these countries have diversified tourist industries, their share of coastal and maritime tourism was important for the structure of their tourism industry and tourism revenue, especially in Germany and Poland. In Germany, 17 % of all overnight stays are recorded in the coastal provinces of Hamburg, Mecklenburg-Western Pomerania and Schleswig-Holstein, while in Poland, 43 % of such stays are generated in the coastal regions of Północno-Zachodni and Północny (BSTC 2018).

Unlike most large European tourist markets, the BSR region has a very high share of domestic and intra-BSR tourists. For example, in Germany, where beach holidays are the preferred holiday type, the Baltic coasts in Mecklenburg-Western Pomerania and Schleswig-Holstein are especially popular among domestic tourists. In 2018, 96.1 % of nights spent in tourist accommodation in Mecklenburg-Western Pomerania came from domestic German tourists, which was the highest share of domestic tourists in any region in the EU (Eurostat 2018). The destinations benefit from the fact that around 30 % of German tourists vacation domestically and that 45 % of them drive to their destination (ADAC 2018). Between 2014 and 2016, the direct employment of the BSR tourism industry increased by 6.5 % to a total of more than 650,000 jobs directly provided. The major labour markets are the German Baltic coast with over 180,000 employees, closely followed by Sweden with 173,000. In terms of GDP contributions generated by the BSR tourism industry, tourism generated between 1.8 % (Lithuania) to 4.3 % (Finland, Latvia) of each BSR country's overall national GDP in 2016 (BSTC).

However, this significant economic contribution comes with several socioeconomic challenges attached. To mention just a few, they can unknowingly harm local endemic flora and fauna or introduce foreign species, which can reproduce rapidly with



Managing beach wrack with tourists in mind – Yantarny, Kaliningrad District, Russia (Photo: © J. Gorbunova)

How does one best go about managing beach wrack while catering primarily to tourists? According to the Russian local working group coordinator, we can look at Yantarny in Russia. The beach used to be primarily used by local residents, mostly fishermen and farmers. A gradual expansion of the zone devoted for tourism and recreation has led to the development of a prime four kilometres long stretch of managed sandy beach, which has been awarded the Blue Flag (2020) and highlighted as a destination in tourist catalogues. Steady investments in the beach's tourist infrastructure and marketing have been bringing increasing levels of revenue for its owners, the local municipality, as well as the local hospitality sector. The area is world famous for its amber ("yantar" in Russian), with around 90 % of the world's reserves estimated to be located here. Amber collection is also a major tourist activity during the season, when tourists collect it from the beach wrack. Even so, the entire beach and the wider area are cleaned regularly. This has led to concerns about biodiversity and sand erosion in the area. Like with many others, the beach's ability to withstand climate change and extreme weather events is likely to be reduced over the medium and long term.

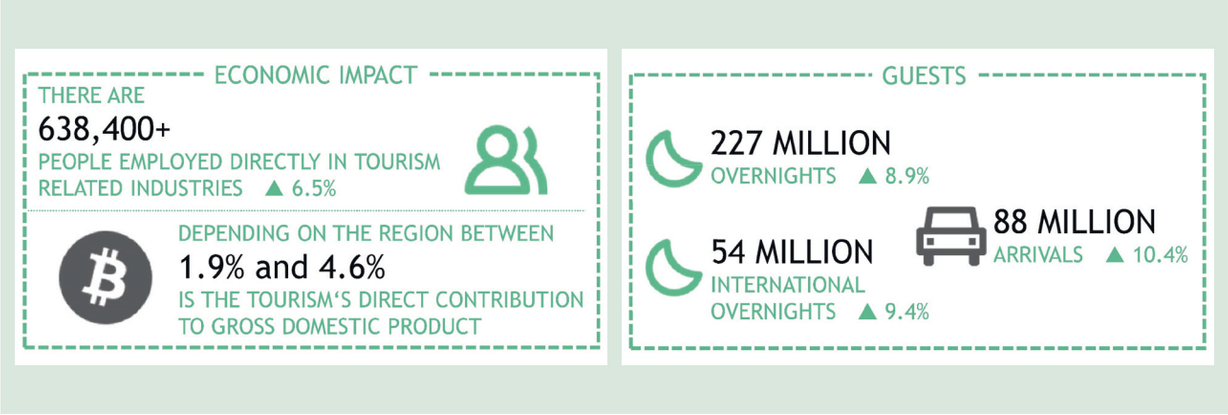


Figure 7 Economic figures and impact of tourism in the BSR, 2014–2016 (© BSTC 2018)

no natural predators and become a pest. Other relevant problems include higher levels of sunscreen oil in the water near the beach and formerly public beach sites limiting access to paying customers only to increase revenue. It also increases the demand for beach grooming and beach wrack removal (Orams 2003).

Land and Beach Use Patterns and Trends

Beach tourist resorts follow fairly similar land use patterns. A large amount of land near the beach is used for real estate development (Smith 1991; Bal and Czalczynska-Podolska 2020), mostly short-term rentals like hotels, apartment buildings, and campsites. The side effects of this can include local traffic congestion, removal of trees, and (over) construction leading to the loss of traditional cultural identity (Bal and Czalczynska-Podolska 2020; Jankauskaitė and Grecevičius 2018). In some tourist resorts, attempts are made to limit or prohibit manmade interference, including zoning to limit building height and density, monumental protection for older and historic buildings, mandatory green space quotas, ecologically protected zones near the beach, and sustainable transport infrastructure like bike lanes (Kropinova 2020). If executed successfully, these measures can alleviate the negative environmental and social side effects of tourism on the local community and help present a more premium image of the resort, as was traditional of BSR resorts in the late 19th and early 20th century (Bal and Czalczynska-Podolska 2020).

Meeting Tourism Sector Demands in the Long Term

Tourism is thus a proven profitable economic activity in the short- to mid-term. However, over time, if the tourism activity destroys the attraction upon which it is based, the entire investment in accompanying tourism infrastructure and businesses is lost. Environmental sustainability is therefore a critical component of the long-term economic success of any nature-based tourism venture such as those based around sandy beaches. Balancing the social and especially economic benefits with the environmental and social downsides of tourism requires a complex and holistic approach. This includes the reconsideration of beach wrack management.

3.3 Impacts of Beach Wrack Management on Tourism (and Vice Versa)

Socioeconomic pressure to promote tourism and recreation activities alters the beach ecosystems of tourist beaches. This also concerns beach wrack management (CONTRA-report Möller et al. 2021). Due to its prevailing culturally conditioned perception as unclean, beach wrack is commonly removed from managed beaches. A key source of socioeconomic pressure is modern social media, where posts are written in minutes or seconds and publicly visible instantly. According to an anonymous BSR municipality representative responsible for beach cleaning and tourism services, this makes it harder for beach managers to have a traditional discussion with tourists who see beach-wrack-laden beaches as a letdown. In turn, it increases the pressure for beach managers to remove beach wrack. While trying to preserve their beach's reputation, they may even begin removing it "preventively", in anticipation of negative reviews (CONTRA – Management Summary Report 2021).

The extent and regularity of beach wrack deposits is affected by weather and the coastal landform. In general, research shows that protected beaches (e.g. behind an island, dam or spit, or with a backshore forest) can accumulate large amounts of



Figure 8 Beach wrack pile on tourist beach (© EUCC-D)

beach wrack that can persist over time. In contrast, unprotected beaches are more exposed to environmental conditions. Larger deposits on such beaches are linked to highest wave heights and stronger winds. Beach wrack deposits at unprotected beaches are more often irregular and can be very large.

his unpredictability on unprotected beaches, which most BSR tourist beaches are, clashes with the predictable behaviour of beach tourists. The latter generally start filling the beaches during the tourist season at the same time every morning. Several beach managers thus indicated in interviews that they must grapple with a difficult dilemma. If extreme weather events result in abnormally large accumulations of beach wrack, the space for tourism and recreation activities can be entirely obstructed, particularly on smaller beaches, for as long as the beach wrack stays in place. For these situations, managers ideally have as much capacity for material removal as possible. The decision regarding removal also has to be taken very early in the morning under time pressure, before the tourists begin to arrive. However, they also have an incentive to avoid costs linked to unused capacities. Most managers we interviewed managed smaller resorts. Correspondingly, the majority of them reported to have a policy of removing beach wrack on demand rather than periodically.

3.4. Summary

To summarize, managed tourist beaches face a complex balancing act between economics, social interests and the environment. These interests can be further broken down. For example, the residents' social interests can often clash with tourist visitors' or small business owners with short-term oriented business models may not see eye-to-eye with beach managers worried about the integrity of their beach. We analyse these various interests in the following sections.



Generating economic revenue through large events – Täppetstranden, Åhus, Kristianstad, Sweden

(Photo: © Kristianstads kommun)

Information gathered by the local CONTRA working group coordinator indicates Åhus is a vibrant summer resort with a lot of visitors, mainly from Sweden, Denmark and Germany. The beaches have a high value for the municipality. The coast is an attractive area for housing, tourism, business and recreation. There is a handful of hotels and a campsite in the village, as well as a lot of summerhouses in the vicinity. The town gets around 2 million visitors every year. Exact numbers on the total economic value are lacking, as it is a complex question. However, the total tourist economical revenue for the municipality is around 900 million Swedish kronor, and the municipality estimates that the Täppestranden beach in Åhus accounts for at least 20 %. On Täppetstranden, beach wrack is removed just once per month between March and August. It is spatially zoned, meaning not all parts of the beach get cleaned. The beach also hosts some of the largest events in Åhus. In 2018, eight major sporting and cultural events, including a melody festival and a beach handball tournament, attracted over 100,000 visitors and generated sales of over SEK 210 million (20.7 million EUR).

4 Public Interests and Behaviour

The best interests of tourist visitors are regularly cited by beach managers as the reasoning behind beach wrack removal. But what are the public's views of beach wrack exactly? How much pressure in favour of beach wrack removal does the public exert? And how do their views affect their tolerance levels regarding beach wrack quantities? These questions are explored in this section.

4.1 Public Perception of Beach Wrack

While millions of visitors are drawn to Baltic Sea tourist resorts every year, the reasons for a specific beach visit and activity choices vary depending on location, infrastructure, beach services provided and several natural conditions.





Figure 9 Large amounts of dried seagrass washed ashore after a storm in Warnemünde, Germany (© J. Hofmann, above); Local residents searching for litter amongst the beach wrack (© J. Hofmann, below)

Tourist Expectations regarding Beach Quality

Results from the Hofmann et al. (in preparation) public survey of around 700 people around the BSR found that the public's first choice of activity is bathing/swimming (→ Fig. 10). This leads us to the assumption that the public's measure of beach quality will largely be related to the beach form, water quality and water access, all of which are impacted by beach wrack management practices.

In practice, public preferences are not homogeneous across beach user profiles. They are most likely to vary between tourists and local residents. Roca et al. (2009) researched this in the Costa Brava area of Catalonia (Spain). They found that, on natural or semi-natural beaches, one more often came across local residents or regional visitors, who were more likely to value peace and quiet. In contrast, at urban beaches, more visitors were tourists, who found manmade beach facilities more important. Furthermore, the findings from an Estonian study of beach wrack socioeconomics point out that Estonian beach resorts tended to develop in locations with low to moderate beach wrack landings, implying a general correlation between managed beach sites and the visitors' preference for less beach wrack (Consulare ÖU, 2021).

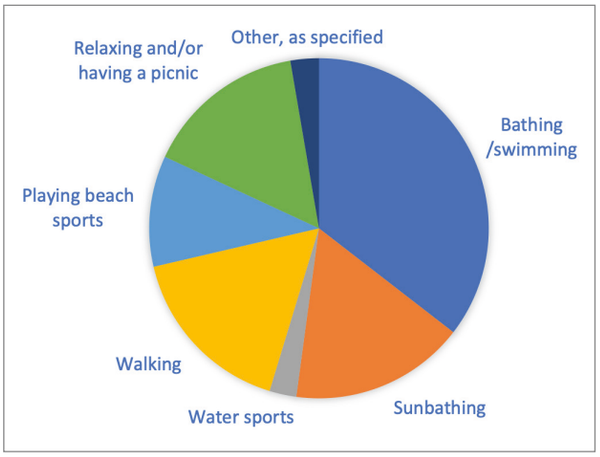


Figure 10 Most important beach activities of the public in the BSR (© Hofmann et al. forthcoming)



Figure 11 Large amounts of marine litter washed ashore (© EUCC-D; above); Decomposing algae on sandy tourist beach, Rügen, Germany, 2019 (© J. Hofmann; below)

Knowledge and Experience

The findings from Hofmann et al. (in preparation) indicate that the ecosystem services of beach wrack are currently not well understood by the general public. On one hand, public experience is high, with nearly all beach goers having come across beach wrack in one form or another at some point. On the other hand, knowledge levels vary per country. Whereas Danish beach visitors were on average relatively well aware of beach wrack's importance to the coastal ecosystem, this was rarely observed by the beach goers in the Kaliningrad Region of Russia.

Awareness of environmental issues and their importance for people and the planet is steadily increasing. However, this is much more often the case for highly publicised issues, such as climate change, rising sea levels, oil spills, and nuclear accidents. On beach wrack, the distribution of official public information from the responsible authorities is virtually non-existent (CONTRA – Management Summary Report 2021).

Examples of public complaints about large amounts of beach wrack

- It reduces beach area available for recreation;
- It impairs the bathing experience with unpleasant odours;
- It obstructs access to the water;
- When dry, it's hard and uncomfortable under bare feet
- It can be populated with sand fleas and other small creatures

Figure 12 Some public complaints about large amounts of beach wrack from CONTRA anonymous public interviews

Public Perception of Beach Wrack Hazards

In 2019, a man died at a beach in the French coastal region of Brittany (Chrisafis, 2019). The beach was inundated by green algae due to nutrient dumping by local agricultural undertakings (especially nitrates from fertilizers). The man stepped on decomposing beach wrack with a high green algae content, which had trapped pockets of toxic gases created during decomposition. These gases later fatally intoxicated him. Such events grab media headlines and have a potentially major impact on the public perception of beach wrack. It is worth noting though that in most cases, beach wrack will not release enough toxic gases during decomposition to physically harm humans. Interestingly, the respondents of an Australian study express an even bigger concern about beach wrack's impact on marine biota than on their own health (Campbell et al. 2016). Thus, other, relatively minor concerns for tourists' health and safety, can take up more attention than potentially deadly rotting algae.

Information and guidance for local authorities on the hazards associated with beach wrack is scarce. It is thus perhaps understandable that beach managers act with an air of caution and that the public is uncertain about potential risk factors. According to Hofmann et al. (in preparation), many interviewed BSR beach goers said that beach wrack is dirty and that they didn't know whether beach wrack can be hazardous. However, the study also indicated that direct experience, impact on activities, and (to some extent) knowledge play a role in public perception. Indirectly, experience also helps shape the public's tolerance levels.





Figure 13 Litter contamination of beach wrack (© J. Hofmann; above); Land sourced litter trapped in drying beach wrack (© J. Hofmann; below)

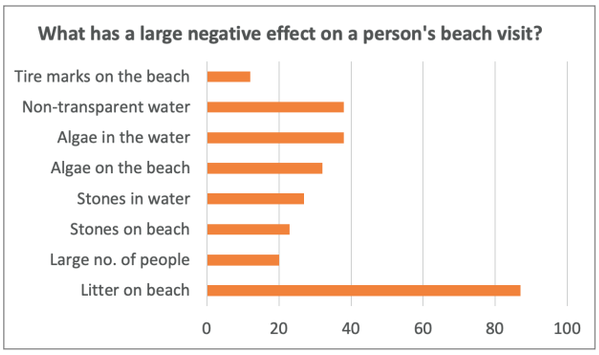


Figure 14 Percentage of respondents who say that certain occurences have a notable negative effect on their beach visit (© Hofmann et al. forthcoming)

Unlike municipal beach cleaning operations, the public makes a clear distinction between anthropogenic litter and natural beach wrack. Hofmann et al. (in preparation) indicate that litter and beach wrack are indeed perceived very differently. While algae on the beach does have a negative effect on many beach visits, it is still a secondary problem compared to litter (→ see Figure 14), which is seen as overwhelmingly more problematic.

4.2 Public Tolerance of Beach Wrack

Using various beach wrack photos (shown below), the Hofmann et al. (in preparation) public survey aimed to improve the understanding of how tolerant people are of beach wrack on BSR managed beaches and whether current beach cleaning operations are meeting beach-goers' expectations.



Photo A: Managed sandy beach with no beach wrack.



Photo B: Managed sandy beach with wide (> 2 m) line of beach wrack lying at waterline.



Photo C: Managed sandy beach with narrow line (< 1 m) of beach wrack lying along waterline.



Photo D: Managed sandy beach with narrow line (< 1 m) of beach wrack lying up the beach.



Photo E: Managed sandy beach with sporadic clumps of old beach wrack over the whole beach.



Photo F: Managed sandy beach with beach wrack covering the whole beach.

Figure 15 Various beach wrack photos used in the CONTRA public survey

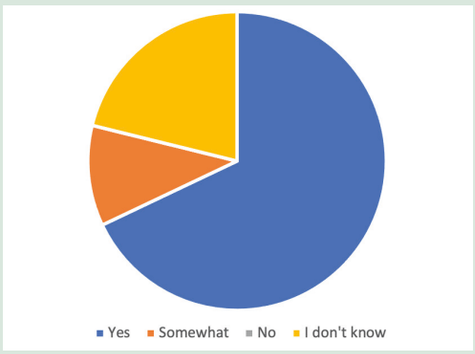




Figure 16 Beach cleaning satisfaction at Täppetstranden, Åhus, Sweden | (N=156, left; conditions similar to photo A, right)

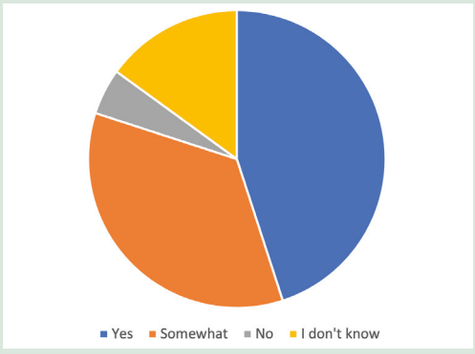




Figure 17 Beach cleaning satisfaction at Puck City beach, Poland | (N=20, left; conditions similar to photo E, right)

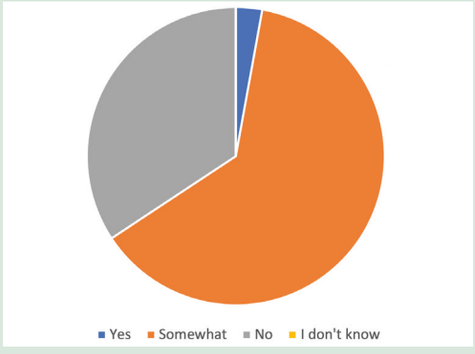




Figure 18 Beach cleaning satisfaction at Suchacz & Tolkmicko, Vistula lagoon, PL | (N=35, left; conditions similar to photo B, right)

Findings from over 700 filled-in public questionnaires indicate that, while beach wrack does not have a notably positive effect on a person's beach experience, respondents do feel neutral about small amounts that they can walk around or step over. The surveyed are fairly tolerant of beach wrack conditions similar to photo E (→ see Figure 15).
The study showed that there is a notable difference in tolerance levels depending on location. For example, beach goers in Germany are more accepting of beach wrack landings than their counterparts in Poland. People's direct experience and (to a lesser degree) knowledge also appear to play a role. In the areas where knowledge about eco-system services is lower, tolerance levels tend to be lower as well. Other factors at play that contribute to differences in tolerance levels include the general appearance of a beach, upkeep of facilities, effectiveness of litter management and marketing of the beaches.

Beach Cleaning Satisfaction

Just as the perception and tolerance levels of beach wrack vary, so does the acceptance of beach cleaning operations. Hofmann et al. (in preparation) indicate that most respondents are satisfied with cleaning that still leaves a narrow line of beach wrack by the water line (→ see Figures 16–18). However, larger amounts of beach wrack present questions



Figure 19 Kite surfing beach with beach wrack (© J. Hofmann)

of health, safety and aesthetics. Correspondingly, beach cleaning satisfaction is lower under this type of beach-wrack-heavy circumstances. A balance from the tourists' perspective probably lies somewhere in the middle. They seem to mostly approve removing some beach wrack, but not always the systematic removal of all of it.

4.3 Public Impact

It should be noted that beach wrack is only one of many factors that impact the public's activity and destination choices. Indeed, it is one of relatively small importance; the public names litter and algae in the water as factors likely to have a much more important negative impact on their experience than beach wrack (→ Figure 14). Nevertheless, it does have an impact, which merited consideration in the CONTRA public survey.

Activity and destination choices

Beach wrack is more likely to affect activities that are bound to the beach, such as volleyball sporting events, much more than those requiring access to the sea like swimming.

The Hofmann et al. study (in preparation) also surveyed BSR beach goers on the basis of several beach wrack photos (→ Figure 15) and the impact they had on their choice of activity. While a narrow line of beach wrack that can be stepped over or walked around was tolerated by swimmers, any line wider than a meter already had a dissuasive effect. The study notes the high importance of the conditions of the day for the respondents' answers. If a beach was filled with beach wrack, respondents gave it much more consideration than on beaches virtually free of it, where it was just a side thought.

Impact of the internet

The advent of the digital age has brought about the increased use of the internet, including online booking services and social media channels. Alongside other parallel socioeconomic developments, these have had some notable impacts on BSR beach tourism. Firstly, they have made it more international and larger in scope. The multilingual experience offered by major booking providers have made comparison of prices and amenities across destinations simpler and readily available to tourists in their native tongue. The drawback of this is that international tourism has been linked with a more negative impact on happiness of the local population than domestic tourism (Okulicz-Kozaryn and Strzelecka

2017). Next, the importance of the image of the resort and complying with tourist expectations has increased. In unstructured interviews, beach managers at the CONTRA case study sites said that they felt under pressure to present their beaches similar to the well-groomed Caribbean ones being represented in the media. Indeed, this shift has also made their way to their traditional marketing material. Social media and user generated content are a major source of such pressure, as they allow tourists to easily communicate their experiences to one another and indirectly influence the travelling expectations of potential future tourists. However, while tourists may have "Caribbean" expectations of BSR destinations, the beach wrack dynamics in the BSR can be quite different, presenting more complex management challenges which tourists do not consider. For example, concerns about cohabitating and preserving local traditions become more sidelined. From the managers' perspective, the extent to which tourist expectations are met will eventually determine the level of tourist satisfaction. If the overall performance while or after visiting a destination exceeds or meets the initial expectations, the tourist is considered satisfied (Narangajavana et al. 2017). Inevitably, some tourists will see beach wrack negatively and will continue to do so despite the feedback from experts. Social media channels are especially prone to amplifying these negative voices (Ott, 2017). In summary, the internet age has brought about new dynamics for BSR beach managers, which have presented new social and economic challenges, including those related to beach wrack and other beach conservation concerns. In the long-term, researchers predict that coexistence between beach conservation and touristic activities will require a socio-cultural change (Rotini 2020).

Culture, Heritage and Local Identity

Various beach wrack management traditions can be found along the Baltic coast. On one hand, we have the more recent one of all-encompassing beach wrack removal from managed beaches. Stemming from the notion of preserving the "traditionally clean" reputation of the beach resorts in question, this tradition is in large part based on the misconception that virtually all beach wrack is inherently dirty and to be classified as waste. On the other hand, there is the previous tradition of cohabitating with beach wrack. This implies not noticeably interfering with the natural processes of which beach wrack is part while reusing the material for various every day or dedicated purposes. An example is the use of beach wrack for traditional biological roofing in Denmark. Historical sources indicate that other methods of traditional reuse of seagrass included using it as an insulation material, mattress filler, cattle bedding, livestock fodder, and tobacco supplement (Heywood 1996; Heimatmuseum Warnemunde 2020; Læsø Museum n.d.).

In general, there are several arguments in favour of promoting local, regional or national identities by keeping these traditions alive and by preserving them for posterity. This is particularly so where traditional beach wrack management policies promote reusing beach wrack with a social and/or economic benefit for beach goers. Ideally, they also aim at minimizing the negative impacts on the beach environment during collection and removal. However, it could be the case that traditional beach wrack practices can also have a net negative effect on the local environment if it leads to unnecessary removal of beach wrack and sand in the name of cleanliness. The question thus arises of what tradition(s) there are to protect, and which ones should be given priority.

The option of cohabitating with and sustainably using beach wrack will, in most cases, be financially cheaper in the short-term, as it requires less intervention that costs managers money. Assuming that the local beach wrack is not polluted or contains large amounts of nutrients or litter, this option also seems optimal from the perspective of preserving the ecosystem services for the society and environment. While beach managers can choose to pursue such an approach on their own, appropriate advocacy and citizen education activities would probably help to promote such a mindset shift in the eyes of tourists and other beach users as well. The latter two currently tend to lean in the direction of pressuring beach managers to preserve the more recent tradition of large-scale, mechanized removal.

Blue Flag Scheme

Another factor driving some beach wrack managers to remove beach wrack are beach award schemes. The Blue Flag award is likely the most famous such award, seen as a marker of a reputable, high quality beach environment suitable as a beach tourism destination. It is considered a valuable asset for any tourist beach to have and inspires confidence in beach goers that the beach is properly maintained and suitable for vacationing and recreation (McKenna et al. 2011). To receive and maintain the award, the beach management needs



Managing beach wrack in a dynamic cultural milieu
City beach, Puck, Pomerania Province, Poland (Photo: © D. Szponder)

Puck is the seat of the municipality of the same name in the Hel Peninsula on the Baltic coast of northern Poland. The town has 11,000 inhabitants. Our local working group coordinators describe it as a seaside resort as well as a local cultural center. The guarded sandy beach in Puck is 100 meters long and 30 meters wide. It is located just a few minutes' walk from the city centre. The city beach plays a significant role in social integration, serving as a space where age categories or social and economic divisions become secondary. The beach is used as sports and recreation in the summer for leisure and year-round meeting places for residents (pier, beach). The area also has historical and religious value going back a thousand years. A walking pier is used for cultural and social purposes as a meeting place. Various local groups join in cleaning and caring for beaches, including scouts, kindergartens, and elementary schools. This is related to learning about caring for the environment and cyclical events such as Earth Day, combining issues of pro-ecological education and increasing local social activity. The coastal area also has a religious function. A pilgrimage of people to the sea is organized in Puck and is becoming an independent tourist attraction. It is one of the most important events taking place in this city and dates back to the 13th century. In its current form, the pilgrimage was revived in 1981, when fishermen from Kuźnica and the entire Hel Peninsula set out on fishing boats to Puck. Finally, every year, a celebration of Poland's marriage to the sea a reenactment takes place on February 10. The event gathers hundreds of participants commemorating a major regional and national historical event, when General Józef Haller (Polish national hero) symbolically marked Polish "marriage to the sea" in 1920. To this day, the general's monument and the nuptial post stand to commemorate this.

to go through an application process and ensure that the Blue Flag criteria are met and complied with on a regular basis. Among the surveyed beach managers, we commonly observed the idea that removing beach wrack results in cleanliness, which is essential to preserving a beach's legal status as a Blue Flag beach. The legal situation is, in fact, more complicated, with the rules often being quite ambiguous.



Figure 20 Blue flag flying on a beach (© J. Gorbunova)

For example, Criterion 16 of the Blue Flag Beach Criteria (BFF 2017) is named "Algae vegetation or natural debris should be left on the beach". It states:

"Algal vegetation is generally accepted as referring to seaweed. Seaweed and other vegetation/natural debris are natural components of both freshwater and marine ecosystems. These ecosystems must be considered as living and natural environments and not only as a recreational asset to be kept tidy. Thus, the management of seaweed or other vegetation/natural detritus on the shore should be sensitive to both visitor needs and biodiversity ... Vegetation should not be allowed to accumulate to the point where it becomes a hazard. Only if it is absolutely necessary should vegetation be removed ..."

Thus, the scheme is not very specific on the matter of beach wrack. As it does not clearly define it, it leaves a lot of legal leeway for the managers to define what a hazardous point of accumulation is and when biodiversity considerations become more important. This makes its usability as concerns beach wrack limited. Indeed, arguably, the scheme's main purpose is to provide concrete guidance and to make these decisions more science-based and less arbitrary. Furthermore, beyond the legal aspect, managers would appreciate guidance on what is a recommended or safe amount of beach wrack to keep on the beach. This would help them streamline removal operations. The same goes for determining and informing what amount is or should be widely tolerated by the general public.

4.4 Summary

The public opinion and the way it shapes public perception and tolerance of beach wrack is an essential driver of beach wrack management policy. Beyond age-old valid concerns, such as beach goers' health and safety, digitalization and internationalization have generally contributed to making the overall perception more negative and reducing tolerance levels. In the long term, effective communication is almost certain to help accelerate the shift in public's expectations of a quality beach from one cleaned and devoid of organic material towards a beach in its natural or close-to-natural state. This would result in less demand for beach wrack removal and allow managers to introduce further zoning (spatial and temporal) to reduce long-term environmental damage by heavy machinery. From this study, beach managers can be assured that it is not always necessary to completely remove all beach wrack for beach goers to enjoy their beach- and water-related activities and their stay in the tourist resort in general. Gauging the attitude of the local visitors and providing information material on the socioeconomic importance of beach wrack is likely to tilt the balance towards removing less. However, the specific composition of beach wrack and other local socieconomic and legal factors may sideline the tourist perspective when it comes to the final decision regarding the quantity that is removed.

5 Public Health and Safety

Other important decision-making factors for beach wrack managers are health and safety concerns. The state beach wrack finds itself in is crucial to determining if and how much of it should be removed. Beach wrack can be contaminated with bacteria, unhygienic marine litter, or pollutants such as mercury and other heavy metals, all of which can be risky to human health (see below). Litter within beach wrack can originate from various sources, both from the sea and from the land. It is not unusual to observe that litter previously dropped by beach visitors becomes concealed by the freshly washed up beach wrack. Litter on the beaches commonly includes glass bottles. Consequently, sharp edges that are difficult to see may be mixed in beach wrack or sediment, presenting an injury risk. In addition, toxic gases that occur during decomposition of beach wrack with a high algae content can result in severe health issues.

5.1 Toxic Decomposing Gases

If left untreated on the beach (especially on the foreshore) for a long time, beach wrack is exposed to the sea waves and tidal effects, keeping it wet. Under such conditions, the disintegration process can lead to beach wrack with a high algae content to become rotten and smelly. Due to the release of ammonium gases and hydrogen sulfide (H_2S) during decomposition (Lastra et al. 2018), such beach wrack has a smell similar to rotten eggs which is undesirable for beach goers. Inhaling ammonia can cause coughing and nose and throat irritation. While ammonia's odour provides adequate early warning, it also might cause olfactory fatigue or adaptation. This reduces one's awareness of prolonged exposure to low ammonia concentrations (NYSDH 2005), potentially increasing health risks. Furthermore, decomposing beach wrack can be unpleasant to walk through due to its gooey texture and the increasingly intense odour as one comes closer to its source.

In extreme cases, decomposing beach wrack that released hydrogen sulphide has even proven deadly (Chrisafis 2019) in France. Such beach wrack has a high green algae content and only washes up in critically high amounts in regions with intensive agriculture and industrial sectors. There, the level of nutrients in the water, especially nitrates found in



Figure 21 Photo of decomposing beach wrack with fine particulate algae matter and slime (© J. Hofmann)



Figure 22 Land sourced litter trapped in drying beach wrack (© J.Hofmann)



Figure 23 Local volunteer picking litter from beach wrack (© J.Hofmann)

fertilizers, is higher. It should be noted that such phenomena have not yet been observed in the BSR. In the long-term, reducing the amount of nutrients and pollutants flowing into coastal waters, including the Baltic Sea, is needed to address this problem. A concerted effort by Baltic Sea nations, in line with the targets laid out in international frameworks such as the Water Framework Directive (WFD) and the EU Strategy for the Baltic Sea Region (EUSBSR), has gone a long way to improve the water quality situation. However, according to the most recent HELCOM report (2020), eutrophication levels remain unacceptable with a lot more work still to be done. Extreme algae events should alert the local authorities to the shared responsibility that exists for water quality within the region. CONTRA findings have corroborated previous scientific findings that removing beach wrack also contributes to removing harmful excess nutrients from the local ecosystem (CONTRA-report Möller et al. 2021).

5.2 Litter

Litter dropped by visiting tourists or washed up on the beach can carry a health and safety risk. An Australian study reports that, even in beaches considered clean of litter, 21.6 % of respondents report having experienced injuries due to beach litter, with cuts and wounds being most common (Campbell et al. 2016). These injuries tend to be relatively minor, with little to no permanent damage. However, they can have a significant detrimental effect on the overall vacation experience, particularly if they involve hospital visits due to an infected wound. Litter can also be problematic for pets, causing injuries or poisoning. This increases the incentive for beach managers to groom their beach, removing litter and – something rarely considered separately by beach managers we interviewed – beach wrack. In practice, the amounts of litter washed up within beach wrack on BSR beaches are generally reported as being very low (CONTRA-report Möller et al. 2021). Indeed, on a European level, the Baltic Sea beaches are regarded as some of the cleanest ones (HELCOM 2018a). Most of the litter found on the European beaches is plastic-based. On 18 sites periodically surveyed by CONTRA between 2019 and 2021, the share of plastic material among others was 72 %, 9 % for glass and 6 % for metal (CONTRA-report Möller et al. 2021). Most common findings were cigarette remains, plastic pieces, food containers and candy wrappers, plastic bags, plastic bottle caps, glass fragments, glass bottles and jars, plastic rope (pieces), plastic foam sponge, metal caps and pull tabs. In accordance with earlier similar studies, most of the litter found on the public beaches is related to simple leisure activities and originate from land-based sources (Addamo et al. 2017). The amounts of litter increased proportionately to the level of urbanization of the surrounding area. Even in these cases, most beaches complied with the criterion of up to 20 items of beach litter items for every 100 metres of coastline, which is agreed to represent a good environmental status of beaches litter-wise at an EU level (Van Loon et al. 2020).

5.3 Heavy Metals

Heavy metals, including arsenic, cadmium, chromium, copper, lead, mercury and zinc, are a major environmental problem due to their toxic nature, non-biodegradability and accumulative behaviour. They originate mostly from industrial, agricultural and hydrocarbon-related activities, shipping and sewage. Once in the coastal and marine environments, they accumulate in sediments and soils. Thus, heavy metals concentrations in coastal areas around shipyards, ports and industrial sites often far exceed health and safety limits. This can negatively affect marine biodiversity, hurting the populations of fish and other organisms. Due to their persistence in the aquatic food chain, heavy metal contamination ultimately affects human health (Sharifuzzaman et al. 2016).

The main threats to human health from heavy metals are associated with exposure to arsenic, cadmium, chromium, mercury and lead (Järup 2003). Arsenic and chromium are classified in the US as priority pollutants and human carcinogens, while cadmium and lead are classified as probable human carcinogens (Pekey 2006). Heavy metal poisoning can lead to severe physical and mental health issues (McCluggage 1991). Long-term exposure to heavy metals can cause severe conditions, including kidney and skeletal damage, memory deterioration and loss of cognitive functions (Järup 2003; Young 2005, Rossi 2008).

In general, the content of heavy metals in BSR beach wrack is still to be precisely determined by field research. Nevertheless, CONTRA has started making the first inroads (CONTRA-report Möller et al. 2021). Heavy metals have been detected in beach wrack found along beaches close to the estuaries of major rivers flowing through large, old industrial areas, notably in Poland. The amounts within the sediment found close to beach wrack were generally higher than in other parts of the managed area on Polish beaches sampled by CONTRA. However, the differences were not significant in most cases. The exception were zinc and chromium in Puck Bay. There, chromium and zinc levels were significantly higher in sand collected below beach wrack. In addition, the total concentration of mercury in beach wrack was higher than in the living algae from the area, indicating continuous absorption of this metal by beach wrack from the surf water after the deposition. It is to be noted that the exact content and levels of heavy metals found varies and has to be determined at each case site individually. Thus, it is difficult to provide any concrete indications on whether it is dangerous to human health in the BSR in the short or the long run.

5.4 Bacteria

Studies from non-BSR countries, including Australia and Great Britain, have shown that beach wrack could be a reservoir of fecal indicator bacteria (FIB), including Enterococci and *Escherichia coli* (Imamura et al. 2011; Whiley et al. 2018). FIB concentrations in beach water are monitored routinely throughout the world in an effort to protect public health. Direct exposure to FIB has been linked to human health risk (Heaney et al. 2009). However, a study conducted in California on multiple beaches has concluded that beach grooming or the removal of beach wrack does not have any impact on reducing or even increases the amount of FIB found in the nearby waters. This would mean that beach grooming is not justified as a microbial pollution remediation strategy (Russell et al. 2014). Further inquiry is required to identify the exact impact of beach grooming on bacterial presence in the BSR.

5.5 Microplastics

A further burden on the environment and thus also a threat to the health of humans as end consumers are microplastics. Every year, 5–14 million tons of plastic flow into oceans globally (Jambeck et al. 2015).

The widespread degradation and breakup of plastic is one of the key factors causing the build up of microplastics in the marine environment (GESAMP 2016) and they have been proven to have caused harm or death to marine fauna, biota and seabirds (Chatterjee and Sharma 2019). The toxins found in microplastics have also found their way to human bodies (Cox et al. 2020). However, the impact they have on public health is still being researched. Data from the Russian Baltic region of Kaliningrad indicates that there are no meaningful differences in the amount of microplastics found on beaches with a high and low anthropogenic load, and that these amounts do not drastically differ from those at other BSR beaches (Esiukova 2016). On the coast of Poland, no clear difference in microplastic contamination between urban beaches and national parks was noted either (Urban-Malinga et al. 2020). However, these areas of the Baltic are rather exposed and the coastline is straight. This is rather different in north-east BSR, which is much more diverse in coastal morphology and thus also has more sheltered and thus litter accumulating beaches. Preliminary results indicate that there, the rather



Figure 24 Decomposing beach wrack (© J. Hofmann)

sheltered urban beaches do contain more microplastic particles in the sediment than natural ones in remote areas (Urban-Malinga et al. 2020).

5.6 Summary

In certain circumstances, there are valid health and safety reasons to remove beach wrack. The first is possible contamination with litter and other pollutants undesired within the beach ecosystem, such as heavy metals (CONTRA-report Möller et al. 2021). Second, in case excessive amounts of nutrients are present in the beach wrack, removing it can help reduce the effects of eutrophication and the overgrowth of micro-algae in coastal waters. Third, removing beach wrack eliminates the problem of decomposing gases, which can be a risk to the health and safety of beach goers. This is indeed a prerequisite for tourism, recreation, and any other human activity at the beach. However, the removal of beach wrack on health and safety grounds should be done on the basis of data gathered through beach monitoring with local marine ecology experts. This helps managers follow best beach wrack management practices.

Overall, health and safety facets incentivize (drive) beach managers to remove beach wrack even if there is no evidence to suggest that it is contaminated or it is dry and not decomposing. There is a pressure for them to act, as they would like to ensure safe and healthy tourism and recreation for their visitors. However, the ensuing systematic removal of beach wrack changes the state of the beach ecosystem and the positive ecosystem services generated by beach wrack. The negative long-term impact of this can be an overall loss of beach value due to reduced biodiversity, loss of sand, and decreased resistance to extreme weather events. This would not only be negative for the local ecosystem, but for tourism and recreation usage as well. There are measures available to at least partially rectify this (e.g. importing sand, creating artificial dunes, water management through dams, reforestation etc.). However, they usually come at a high financial cost and involve manipulating the local environment in a way that could have other undesired side effects. A more detailed look at potential hazards, based on the findings of the environmental assessment undertaken at the CONTRA case study sites, can be found in the CONTRA-report Möller et al. 2021.

6 Coastal Landscape and Conservation

Another aspect of beach management affected by beach wrack is coastal landscape and conservation. The state of the coastal ecosystem at sandy managed beaches is dependent on landscape factors such as a consistent presence of sand, stable sea levels, and predictable meteorological impacts. All of these are affected directly and indirectly by beach wrack management.

6.1 The Challenges of Sand and Beach Erosion

In the BSR, tidal ranges are generally very low. The Baltic Sea is neither large enough to have significant own tides nor does it receive much of North Atlantic tides due to the narrow opening to the North Sea (SMHI 2014). The tidal range in the South Baltic region is exceptionally low, making it nearly tide-free. Thus, the only forces that can act on water-born drifting or beach-cast wrack are wind, wind-driven waves and near-shore currents. In practice, the latter are virtually irrelevant. Compared to tidally influenced beaches, wind-driven changes in wrack distribution happen more slowly, depending on weather conditions, and less predictably. Thus, the location of wrack deposition entirely depends on the wind-controlled water level and varies unpredictably within days (Hammann and Zimmer 2014). Marked short-term changes in water level, corresponding to both wind direction and speed and accompanied by high variation of beach width, demonstrate their strong influence on small-scale hydrology and topology ashore.

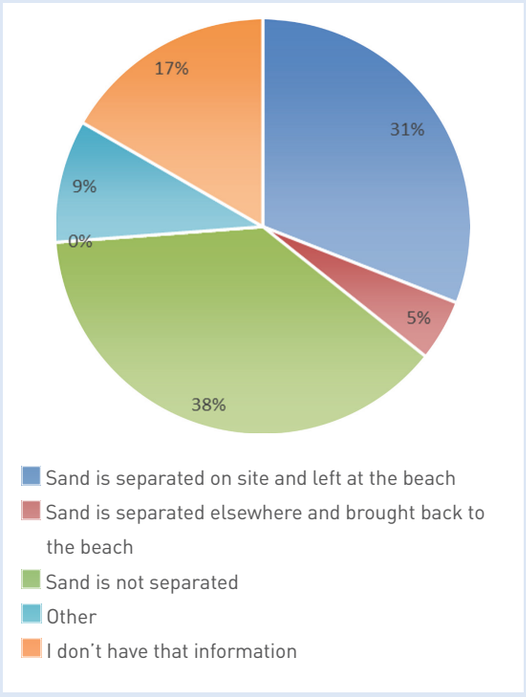
Since the condition and size of a sandy beach is crucial for the tourist attractiveness of the adjacent resort, erosion can potentially threaten the resort's socio-economic functions. While it is possible to replace some of the lost sand, sand nourishments to combat erosion are expensive as sand availability in some Baltic regions is limited. In 2011, an average of 5 million € per year was spent on sand replenishment by federal (30 %) and state governments (70 %) in Germany alone (Haller et al. 2011). Interestingly, findings from the CONTRA beach wrack manager survey (CONTRA – Management Summary Report 2021) indicate that over 30 % of BSR municipalities separate sand on the beach and thus avoid removing it. At the same time, over a quarter of the responding sites reported that they do not separate sand at all. The proportion of sand in dry weight of beach wrack being removed from beaches can be as high as 97 % with an average of 58 % (CONTRA-report Möller et al. 2021). Unless beach management practices are altered to reduce beach erosion of managed beaches, the costs of mitigating it erosion are likely to increase rapidly as the availability of sand diminishes and the demand



Figure 25 Breaking wave on beach wrack (© J. Hofmann)



Figure 26 Sand nourishment in progress (© EUCC-D)



Sand separation statistics: How is collected sand dealt with? (Chart: © CONTRA)

CONTRA findings indicate that the majority of municipalities do not separate out sand when collecting beach wrack (CONTRA - Management Summary Report). Out of 42 surveyed municipalities, 13 (31%) state that they attempt to separate sand and leave it on the beach whereas 16 municipalities (38%) do not make an effort to separate sand at all.

increases. Thus, there is a good financial (as well as environmental) reason beach managers should consider sustainable beach wrack treatment options. CONTRA findings indicate that sand erosion is probably the biggest single impact of beach wrack removal.

6.2 Preparation for Climate Change Impacts

Climate change should be considered in future planning of tourist resort management.

Catering for tourism trends and expectations

In the short-term, due to the ongoing coronavirus pandemic, the importance of domestic tourists and intra-BSR vacationing is likely to increase whereas international tourists reliant on air travel are likely to be less important. In the mid- and long- term,



Alleviating sand erosion through beach wrack management policy Timmendorfer Strand, Island of Poel, Mecklenburg-Vorpommern, Germany
(Photo: © EUCC-D)

CONTRA has interviewed the resort management at the Island of Poel, which has adopted a unique approach for one of its beaches, the Timmendorfer Strand. On the managed part of the beach directed at tourist use, they are experiencing sand loss, partially due to the regular grooming during the high season. They have found a way to partially compensate for this loss. The local company they partner with processes and separates the components of beach wrack. The sand they recover is transported back to the beach and discharged. The beach manager has also contemplated shifting beach wrack from one area of the island's beaches to another. This would indeed temporarily further address the problem. However, as the supply of sand in both areas is limited, a local assessment of the long-term consequences would help determine the long-term feasibility of this strategy. At present, local laws currently err on the side of caution and do not support this as a coastal protection measure. The long term environmental consequences of the direct use of beach wrack on the beach is yet to be investigated.

the attractiveness of the area is likely to increase as the global temperatures increase, making colder destinations in the north of Europe more appealing. Due to lower solar exposure in the BSR compared



Figure 27 Storm damage on beach (© EUCC-D)



Figure 28 Beach wrack as a nutrient source for dune plants at the back of the beach (© EUCC-D)

to the Mediterranean, visitors in the BSR are less likely to get sunburned or develop skin conditions, such as sunstroke or sun cancer, from solar radiation. The lower tidal ranges and corresponding lower currents make the sea safer for recreation, which is important to families with small children. In addition, increasing temperatures will allow the tourist season to start earlier and end later, extending the window of opportunity for profitable tourist activities. However, all of these drivers of tourist activity become irrelevant if the main underlying attraction, the managed sandy beach, loses its primary function due to sand loss (Orams 2003).

Coastal Landscape Preservation

Having beach wrack on the beach helps alleviate the effects of beach erosion. As the beach wrack accumulates on the beach, it covers up and stabilizes the sand below. During extreme weather events, this helps keep the sand in place (CONTRA-report Möller et al. 2021). If the beach wrack accumulates higher up on from the shore, it performs this function even better. This holds true since it is not exposed to continuously high levels of humidity, which slows down the rate of decomposition and allows it to stay firmer. Consequently, beach wrack increases the level of protection against the negative effects of climate change, such as sand erosion and rising sea levels. It is also integral to preserving local biodiversity (Defeo et al. 2008). Furthermore, it can be used as an effective tool in creating manmade dunes, which help to additionally shield the surrounding area from the effects of climate change. Finally, floods and droughts can be effectively managed by wetlands and forests, which absorb and provide water as needed, often found in the vicinity or behind the beach. These ecosystems often depend on the biodiversity fostered by beach wrack. This is also true on BSR coasts, where many species depend on beach wrack as a source of food, living space and nursery (CONTRA-report Möller et al. 2021).

Carbon Footprint and GHG Emissions

Beach wrack has a potential application as a carbon sequestration mechanism. Several species of algae found in large wrack accumulations can bind high levels of emissions of CO_2 (Coupland et al. 2007), potentially affecting the functioning of land-sea interfaces. For instance, the high carbon-to-nitrogen ratio makes this algae species a very efficient vehicle for sequestering carbon in the oceans (Smetacek and Zingone 2013; Krause-Jensen and Duarte 2016). The term blue carbon was coined to describe the disproportionately large contribution of coastal vegetated ecosystems to global carbon sequestration. The role of blue carbon in climate change mitigation and adaptation has now reached international prominence (Macreadie et al. 2017).
While beach wrack has a locally beneficial impact from the perspective of climate adaptation and mitigation, it also has a global downside. A Chinese study estimates that decomposing seagrass is responsible for GHG emissions equivalent to those of "the annual emissions of 0.63–9.19 million Chinese citizens" (Liu et al. 2019). These emissions contribute to global warming. This can be reduced by ensuring beach wrack remains dry during decomposition, for example, by moving it up the beach. Furthermore, it can be removed from the beach and stored in dedicated facilities. However, this causes some transportation emissions and



Figure 29 Beach wrack and coastal vegetation (© EUCC-D)

introduces the problem of nutrient leaching. The share of these emissions is relatively small compared to the emissions from industry, transport and agriculture. More information and findings on CO_2 emissions from beach wrack landings can be found in the CONTRA-report Möller et al. 2021.

6.3 Summary

As one of many components of the coastal ecosystems, beach wrack is integral to preserving the natural balance that characterizes the coastal landscape as we know it. How it is managed by humans has an impact on whether that balance is maintained or lost. On managed beaches in the BSR, beach wrack management is especially relevant for reducing the effects of beach erosion. It is also important with a view to alleviating the effects of climate change and protecting biodiversity. On a global scale, reducing the greenhouse gas emissions stemming from decomposing beach wrack also merits consideration.

7 Knowledge and Development Systems

Beach wrack at managed tourist beaches is also important from the perspective of knowledge and development. Coastal environments are complex. While every component plays its own role, the components are in many ways interconnected. Distinguishing the management of a single component, such as beach wrack, in such a system, can be counterproductive if it does not take into account the impact of beach wrack for other aspects of the coastal environment, as well as the local economy and society.

7.1 Integrated Coastal Zone Management

The discipline of integrated coastal zone management (ICZM) has gained importance in recent years. According to the European Commission, *"[ICZM] covers the full cycle of information collection, planning, decision-making, management and monitoring of implementation. It is important to involve all stakeholders across the different sectors to ensure broad support for the implementation of management strategies."* The aim of ICZM is *"the coordinated application of the different policies affecting the coastal zone and related to activities such as nature protection, aquaculture, fisheries, agriculture, industry, offshore wind energy, shipping, tourism, development of infrastructure and mitigation and adaptation to climate change"*. The goal is to *"contribute to sustainable development of coastal zones by the application of an approach that respects the limits of natural resources and ecosystems [through the so-called ecosystem-based approach."* (EC 2020b).

The vast conflicts of interests in coastal areas are making the importance of long-term planning and knowledge transfer ever more important. One consideration of ICZM is beach wrack management. It is most relevant for the wrack zone, a foreshore area where organic material (e.g kelp, seagrass, shells) and other debris is deposited by wave action and currents. This zone acts as a natural input of marine resources into a terrestrial system, providing food and habitat for a variety of coastal organisms (Strain et al. 2018). Thus, the presence of beach wrack helps researchers generate knowledge on various hot coastal and marine topics for ICZM purposes. In the BSR, these include water quality and contamination, eutrophication, coastal protection and soft engineering, and rediscovering sustainable resources as part of bioeconomy initiatives.

7.2 Water Quality

Water governance topics, including water quality, have been the subject of action for the Helsinki Commission (HELCOM). It is the inter-governmental organisation responsible for overseeing the protection of the Baltic marine environment. HELCOM has prepared an action plan to improve the state of the Baltic Sea. The action plan's objectives include addressing eutrophication, biodiversity problems, maritime activities, and hazardous substances. It lays out concrete actions needed to do so (HELCOM 2019).

One indicator for water quality in recreational areas is FIB (Fecal indicator bacteria), as described in section 6.1.4. Beach wrack is seen as a non-fecal source of FIB in sea water (Russell et al. 2014). As with the impact of FIB on human health and safety in the BSR, further inquiry is also required to identify the exact impact of beach grooming on water quality. The existing studies mostly tackle water bodies in the USA and are somewhat inconclusive



Figure 30 Island of Poel, Germany (© J. Hofmann)



Figure 31 Mechanical collection of beach wrack (© J.Hofmann)

on whether beach grooming significantly affects FIB growth (Byappanahalli et al. 2003). It is also not sure how beach wrack as an indicator of water quality ranks in terms of accuracy and practicality. Beach wrack also has several other applications. It helps us understand nutrient balance and nutrient cycles. In beach ecosystems, marine soils "can play a major role in nearshore biogeochemical processes, particularly the decomposition of organic material and mineralization of nutrients. During the summer dry season, beach wrack can be very important to beach ecosystems' ability to accumulate dissolved nutrients needed by primary producers (Dugan et al. 2011). It also helps us understand dune formation and the supply of nutrients to dune stabilizing plants. Finally, it is a useful indicator of biodiversity – monitoring beach wrack availability can help explain changes in endemic avian and crustacean populations at BSR beaches. In addition, the Beach Wrack Macrovegetation Index (BMI) has been developed and tested in the Riga Gulf to measure benthic macrovegetation biodiversity as required by the EU Marine Strategy Framework Directive (Torn et al. 2016). All of these ecological functions and the corresponding ecosystem services are relevant to local communities as well

7.3 Bioeconomy and Marine Resource Management

The European Commission defines the bioeconomy as "using renewable biological resources from land and sea, like crops, forests, fish, animals and micro-organisms to produce food, materials and energy." It expects that "stronger development of the bioeconomy will help the EU accelerate progress towards a circular and low-carbon economy". The Commission also believes that it would "help modernise and strengthen the EU industrial base, creating new value chains" and greening industries "while protecting biodiversity and the environment." (EC 2020c). As part of the EU's political efforts to make European economies more sustainable, multiple documents have laid out targets promoting the blue (marine) economy, circular economy and bioeconomy. They include the EU Strategy for the BSR and the Sustainable Blue Growth Agenda for the BSR (EC 2014a). The former specifies multiple target sectors to promote the Baltic blue economy, various maritime-related innovations and enhanced cooperation in research and fisheries management (EC 2009). Smaller national and local initiatives have also been established with the aim of fostering sustainable, innovative uses of



Exploring beach wrack treatment options Municipality of Køge, Sjælland Region, Denmark (Photo: © One Trick Pony)

Køge is a medium-sized Danish town 39 kilometers southwest of Copenhagen with a population of around 38.000. Our local CONTRA working group correspondents note that the beach is not considered the town's main attraction, as Denmark has plenty of other more famous ones. While the medieval town centre attracts a moderate amount of tourists, Køge is considered a residential town with beach access rather than a resort town. Thus, the local residents have a lot of say in beach wrack management. The municipality beach has a total length of 1.5km, of which 0.9km is managed. During the summer, the municipality provides daily pictures of the cleaned beaches so that visitors can check these pictures before they decide to visit. A lot of beach wrack washes up on the beaches. Presently, it is moved to the unmanaged part of the beach or pushed back into the water. The municipality would like to adopt a more sophisticated beach wrack management strategy in the future. One of the options would be to utilize beach wrack as a compost material in landfill bio-covers. In addition, they could also transport a part of the collected beach wrack to the biogas plant in nearby Solrod. It is important to note that the beach wrack from Køge would make up only a very small side input of around 0,5 % for the biogas plant. The rest comes from agricultural manure, food waste and beach wrack from another beach. It is also essential that the biogas plant is located within a radius of 30 kilometers from the beach because of the transport costs.

local marine resources. Recent growth rates in the BSR blue economy sector are above the EU growth average: offshore wind has increased in the region by 20 %, cruise tourism by 11 % and marine aquaculture by 13 %. The most promising sectors of the BSR maritime economy include short-sea shipping, coastal and cruise tourism, offshore wind, shipbuilding, aquaculture and blue biotechnologies (EC 2014a).

Promoting the bioeconomy in the BSR is also a special focus for the Nordic Council of Ministers. They aim for the Nordic bioeconomy to replace unsustainable and fossil-based resources by upgrading side streams and waste, as well as by creating circular and sustainable local solutions. This goal is part of the grand vision of making BSR the world's most sustainable and integrated macro region (NCM 2020). To this end, BSR economies must become more circular, i.e. reduce new resource inputs and minimize the creation of waste, pollution and carbon emissions. The BSR, especially its eastern countries, have a lot of room for improvement in this regard (Grigoryan and Borodavkina 2017).

The BSR can become a global leader in green growth and sustainable development. It has "well-developed infrastructure, technological and environmental knowledge and a large concentration of biomass". The bioeconomy offers many new economic opportunities, especially for growing primary industries and new development in rural areas. Ongoing projects promoting the BSR bioeconomy tackle topics such as slurry acidification of soils, manure governance, water management, forestry, food webs, and coastal fishing (NCM 2020).

A subject that could also feature in BSR bioeconomy discussions is beach wrack. In CONTRA, we have observed it can be used as a circular economy input: biomass fuel in biogas plants (see text box). It has also shown promise in agriculture as a low cost and eco-friendly fertilizer and soil improver (CONTRA-report Chubarenko et al. 2021, Sachpazidou et al. 2020). Precisely defining the extent of the potentials of beach wrack would require a lot more research, as work in this direction is merely starting off. However, it can certainly be a resource in the BSR bioeconomy, as the existing and traditional uses described in the report affirm.

Another water governance topic is marine resource management. As mentioned in section 2, a lot of attention is being paid to blue growth, the bioeconomy and the circular economy in the BSR at the macropolitical level. However, according to feedback from our interviewed managers, concrete

policy recommendations for local governance at the municipality level, including beach managers, have so far been scarce. A few good practice examples have been highlighted in this study and other CONTRA outputs.

Beach wrack collected from managed beaches does not have a sufficient economic value to become an independent money-making resource (CONTRA-report Almqvist et al. 2021). The main financial value is the sandy beach itself and the tourist activities that depend on it being attractive, healthy and safe for its visitors. Nevertheless, there is added value to be extracted from beach wrack in waste management, exercising environmentally friendly recycling and usage options, and the removal of nutrients and pollutants (CONTRA-report Chubarenko et al. 2021). However, this remains to be more precisely quantified.

7.4 Summary

Beach wrack has an important role to play in the complex beach environments of the BSR. Among other aspects, it merits consideration in spatial planning, water quality assurance, the bioeconomy and resource management. It also has value for knowledge and education systems. From a research perspective, the presence of beach wrack in the natural environment enables more accurate beach ecology research. The environmental effects it has, e.g. on preserving biodiversity, have an indirect impact on the work of other researchers working with endemic plants and animals. There is also the potential for other uses of beach wrack that may only be discovered through innovation or a new market niche appearing in the future, possibly with government help. Further scientific inquiry into quantifying these benefits is essential in supporting these decision-making processes. For example, understanding the local conditions, such as the presence of pollutants, is key for the local beach managing authorities to make informed decisions on removing beach wrack from a particular area or during a particular time of year.

One possible difficulty in increasing the attractiveness of beach wrack to science and education lies in introducing a distinction between beach management and beach wrack management. Currently, very few of the surveyed beach managers consider beach wrack management to be a standalone beach management activity. Thus, researchers are often unable to gather accurate data on the costs of beach wrack management, as it is not considered by the managers to be separate from other "grooming" activities that account for the majority of the costs, such as litter collection. Similarly, any data on long-term impacts (risk management related to climate change and extreme weather effects, loss of beach value over time, ecosystem degradation, biodiversity loss ...) is not available either, as our data shows it is simply not a part beach managers' finances and their short- to mid-term business models and plans.

To summarise, what CONTRA has ascertained is that, from a social and environmental perspective, beach wrack is an acceptable input for the circular economy. However, from the economic view, it does not generate enough value to support standalone private initiatives. Ventures reusing beach wrack sustainably require public subsidies to succeed. Politicians and beach managers need to decide on a case-by-case basis whether these subsidies are justified given the environmental benefits.

8 Socioeconomic Practicalities of Beach Wrack Management

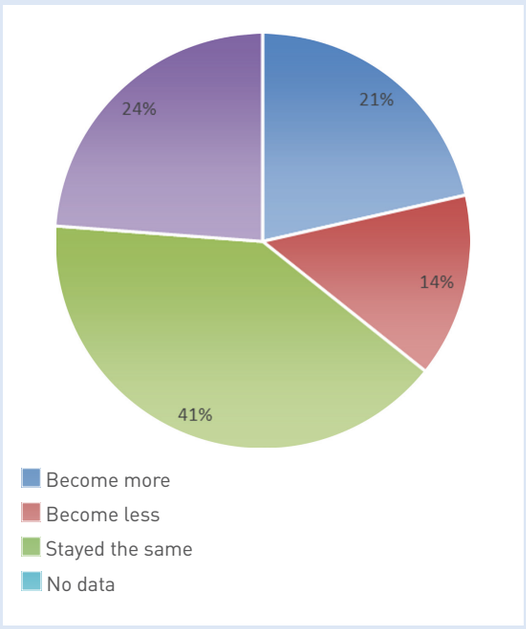
In the following subsections, we look at the socioeconomic practicalities and implications of beach wrack management in the BSR, highlighting best practices and lessons to be learned from our case studies and beyond. Our primary source of information for this section is the CONTRA management questionnaire. It was a semi-structured survey of 42 beach managing authorities from six countries across the BSR conducted in 2019. The respondents were mostly officials of various public bodies, such as municipalities and spa management offices. A minority of respondents came from private undertakings. While the data was gathered for six of CONTRA case study sites, only five consented to their data being publicly available.

8.1 Removal and Collection

In this section, we discuss several options for beach managers to optimize removal and collection from a socioeconomic perspective. Firstly, forecasting beach wrack accumulations effectively would help optimize removal and collection operations. However, in the short-term, forecasting is difficult due to unpredictable weather patterns and lack of data; in the long-term, the big underresearched question is the impact of climate change. Despite this lack of predictability, it is becoming increasingly vital that beach managers begin employing sustainable beach wrack treatment with a long-term perspective. Sadly, overall, there are too many variables and insufficient data to make reliable and



Figure 32 Mechanical beach cleaning (© J.Hofmann)



Statistics on beach wrack trends: What has been the trend of beach wrack quantities over the past 10 years? (Chart: © CONTRA)

The majority of municipalities responding to the CONTRA survey stated that they felt beach wrack quantities have remained the same over the past 10 years. Of the 42 respondents, 9 (21 %) said that quantities have increased whereas 17 (42 %) said they have stayed the same (CONTRA-Management Summary Report).

concrete predictions in the scope of this report. The best managers can do is to rely on a combination of historical data and weather forecasting tools, as they most likely already do.

Beach managers can adopt zoning for the purposes of beach wrack removal. The managers CONTRA interviewed utilize two types of zoning: spatial and temporal. Zoning the beach spatially into managed and unmanaged sections means that the unmanaged sections remain relatively untouched by grooming, with the existing ecosystem mostly unaltered. On managed beaches, there are also various methods of spatial zoning (→ see Figure 30). At the managed sites we surveyed (→ Figure 33), it is more usual for the whole beach to be cleared of material. The unmanaged sections can also be used for temporarily storing the beach wrack from the managed side in small piles. Another possibility that was raised by the interviewed managers

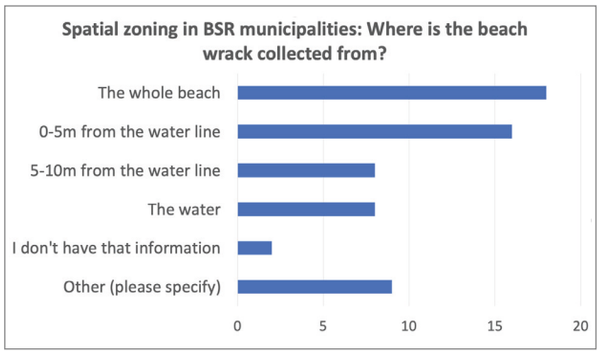


Figure 33 The number of municipalities collecting beach wrack from different sections of the beach, CONTRA management questionnaire (n=42)

was that, in the manner of agricultural crop rotation, the zones could be swapped every season. This would allow one part of the beach to "recover" from grooming while the other is managed to cater to tourists. We note that we do not have any data of this being a current practice. Zoning the beach temporally implies adopting specific time and date intervals for beach grooming. This allows for similar benefits: ensuring the negative impacts of grooming on the ecosystem are limited while also saving costs associated with removal, transport, storage and processing.

Due to clearer cost-saving impacts and practicality, temporal zoning on a seasonal basis is common. In most cases, beach wrack removal is limited to the high tourist season (May–September). In a plurality of the sites studied, short timeframe temporal zoning (→ Figure 34) does not follow a fixed schedule. There, beach wrack is only removed when deemed necessary or on public/stakeholder request.

Small scale spatial zoning on one particular beach is less common and practiced at a minority of sites (ibid). On several German case sites, where a daily beach tax was charged, the frequency of beach cleaning was higher (CONTRA – Management Summary Report 2021).

We detected several particularities among our survey respondents. A pattern was present at beaches that were zoned neither temporally nor spatially: all sites that collect beach wrack daily also clean the whole beach (CONTRA – Management Summary Report 2021). Beach wrack material is also collected in the water prior to landing at nine sites in Sweden, Denmark, Estonia and Germany (ibid). In most BSR countries, this practice is not legally allowed (CONTRA documents – Legal aspects of beach wrack management 2021). Many sites report using a combination of mechanical equipment.

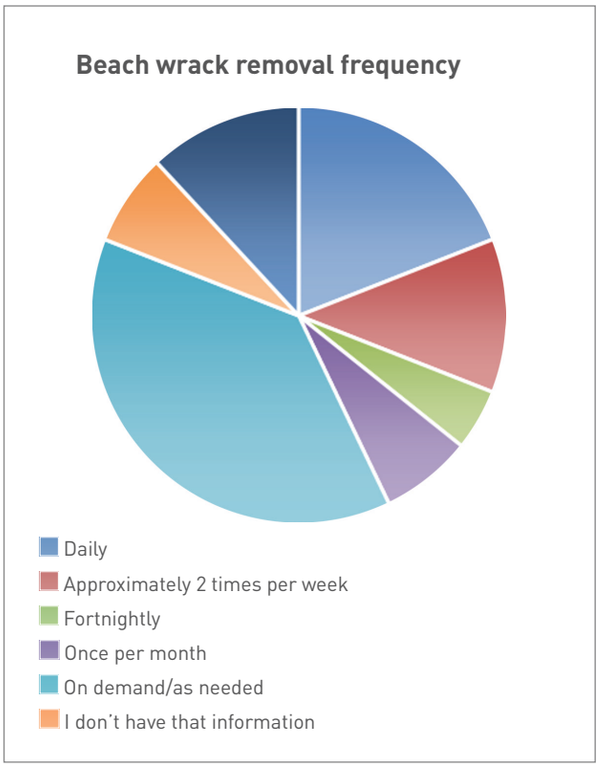


Figure 34 The proportion of municipalities applying different short term temporal zoning to beach wrack removal (CONTRA management questionnaire)

Combining a tractor with a pitchfork and rake is most common.

8.2 Transport, Storage and Processing

CONTRA management survey data indicates that transport, storage and processing merit consideration as cost factors. In this section, we present several best practices and lessons learned from our case studies.

In transport, an important and underestimated consideration is sand weight. Sand is rather heavy (around 1500 kg/m^3), even more so when wet (around 1700 kg/m^3; Rajput 2021). Managers could allow beach wrack to dry on the beach and/or ensure that sand gets separated from the beach wrack that is finally removed. In doing so, they not only do something good for coastal protection and the integrity of their main tourist attraction, the sandy beach – they also save on the weight that has to be transported and thus, on transport costs.

A further way to save here is to reduce the distance to the storage facility. Managers should always be on the lookout for a closer option. Depending on the quantities of beach wrack they face and an environmental assessment, they may use a modified storage facility not primarily meant for storing beach wrack. They could also look into constructing their own facilities or cooperating with nearby farmers who could use beach wrack for fertilization on farmland near the beach. This may, however, pose legal problems due to restrictions regarding direct use of beach wrack due to the unknown composition and possible harmful substances.

Another consideration is noise. While smaller quantities can be removed by hand, beach wrack is generally removed using tractors with purpose-made attachments or dedicated vehicles (CONTRA-report Möller et al. 2021), all powered by diesel engines. They release local emissions, smell and noise, which may disrupt the local flora, fauna and human visitors (CONTRA – Ecological aspects 2021). As the removal takes place outside of the main visiting hours to avoid displeasing the tourists, they tend to annoy nearby residents in the early mornings or late evenings. Both are sub-par options from the residents' view. Beach managers could consider reducing the removal frequency and acquiring hybrid vehicles which can operate in electric mode while on and near the beach. Cleaning frequencies could be reduced if they are presently too high and not directly linked to the demand for beach wrack removal. It should also be mentioned that the beach grooming vehicles could have a scare effect on the beach fauna. However, CONTRA data indicates most birds found on managed beaches are there specifically because they rely on leftover high-energy food from the tourists (CONTRA-report Möller et al. 2021). Only a few natural species were found on such beaches.

Finally, there is the issue of sand compacting. Compacted, solid sand that does not regularly cave in under the feet of people walking on the beach is desirable for recreational users (CONTRA-report Möller et al. 2021). However, compacting the sand mechanically with dedicated vehicles or vibrating plates has a negative environmental impact. It can compromise the long-term integrity of the beach and damage the foot of the dunes. A similar impact, known scientifically as footfall load compaction, can be ascribed to beach users walking on the beach.

With regard to storage, beach wrack can normally be left on the beaches to dry temporarily if an unmanaged section is available and then taken to a dedicated storage facility. While the former is often preferable environmentally and saves on costs, the latter facilitates processing and reuse later on. It is to be noted that German laws are strict on preventing the leaching of heavy metals and toxic content,





Beach wrack challenges on a touristy island
Juliusruh-Breege, Rügen Island, Germany (Photo: © Timo Garrels)

Julisruh-Breege is a small resort town on the east coast of Rügen, Germany's largest island. The data gathered by our working group indicates that the island generates 7.2 million overnights every year (CONTRA – Case studies Report 2021). Juliusruh beach is the island's longest. Of around 8.5 km of the entire beach, 1.5 km is managed. Around 30 thousand cubic meters of beach wrack landings are estimated every year. During the season (May – September), the beach management employs several machines to remove beach wrack. The beach cleaning is done in the evening and early morning to avoid disturbing tourists. The machines are not purpose made for beach wrack and thus not always effective, particularly when there is fine, wet, particulate algae on the beach. The same machines are also used for road and tree maintenance.

sometimes also found in beach wrack, into rain waters (Umwelt Bundesamt 2020). On our case study in Poel, sewage water monitoring at the dedicated beach wrack storage facility has been implemented at the cost of the municipality. National and European grants may also be available for the construction or upgrading of storage facilities with this health and safety risk in mind. This was the case for several municipalities in Mecklenburg-West Pomerania in Germany (Landtag MV 2017).

When it comes to processing, an important and simple first step would be to have a worthwhile strategy and not just throw reusable beach wrack away. To start, the collection stage itself should be reoriented to facilitate effective processing. This would mean acting quickly when fresh material lands on the beach and separating it into distinct, reusable components, which can then be effectively processed by dedicated plants. It would make each processing option more viable. To this end, the managers would have to adopt the mindset that they are collecting and dealing with a resource and not a waste product. Indeed, some forward-thinking municipalities are already achieving progress here. Eckernförde beach managers in Germany have created dunes, fences, municipal gardening fixtures, and added information signs (Schnepper 2017). This has increased the community awareness of the issue. In general, stakeholder cooperation is of great value here. This includes collaborating with other municipalities, companies, experts, NGOs, and lawmakers. It may be possible to create shared storage facilities with multiple managed beach sites and facilitate a recycling company to develop a sustainable business model this way. It would also make negotiations with the company easier.

8.3 Reuse and Recycling Options

Multiple tried-and-tested possibilities for the sustainable use of beach wrack from managed beaches exist (see CONTRA-report Chubarenko et al. 2021). Many social and economic benefits are created in doing so: it contributes to the circular economy, creates jobs and generates revenue for local businesses beyond those catering stricly to tourists. Thereby, it diversifies the local economy, and can offset costs and even generate extra income for beach managers. From the environmental perspective, it alleviates the negative impact of

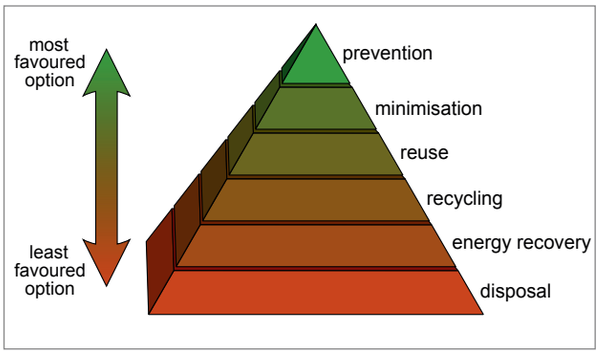


Figure 35 Waste management hierarchy (© Drstuey)



Figure 36 Beach wrack processing at compost plant, Sandhagen, Germany (© J.Hofmann)

removing beach wrack along with the desired removal of litter and nutrients. Potentially generating energy from biogas from a renewable source improves the area's energy sustainability.

A classic use option for beach wrack is fertilizer and soil improvement. Studies have pointed to it being the best use of macroalgae-based beach wrack (Filipkowska et al. 2008). However, this does come with some considerations. For example, it is dependent on the beach wrack's state of decay and its composition, with many potentially problematic components. It also usually involves an undesirable removal of sand from the beach. Similar conditions apply to reusing beach wrack as a soil improver. Other options include using beach wrack that includes seagrass as a matress and cushion filler, making souvenirs, fodder and bedding for livestock, roofing and insulation in construction, cosmetics, biogas, pharmaceuticals and medicine, as well as coastal and urban landscaping. A more comprehensive overview of these possibilities can be found in CONTRA-report Chubarenko et al. 2021. A comparison of the environmental impacts of the various use options, demonstrated within the CONTRA project, can be found in CONTRA-report Almqvist et al. 2021.

There are very few examples of private-public partnerships concerning beach wrack within the BSR that can be looked upon as best practices. Of the 40 municipalities that answered our questionnaire, only two indicated that they have some kind of cooperation in place (CONTRA – Management Summary Report 2021). The first was Solrod in Denmark, where the beach managers deliver their beach wrack to a local biogas plant, which processes it into energy. The second was the aforementioned Island of Poel and a local fertilizer company, Hanseatische Umwelt CAM GmbH (HU), who worked on beach wrack business development during the CONTRA project.

The company has built relations with local municipalities including Poel, and is now processing beach wrack from four beach spots (in four municipalities) within a radius of approx. 50 km. The company processes beach wrack into various soil improvement products. This is a promising outcome, as it offers a way to process beach wrack into environmentally sustainable outputs while ensuring the collection and processing takes place with a high cost efficiency. It also can be done at a scale which allows beach wrack to be resold for additional income.

The fact that this business model remains unique highlights several problems. Namely, the irregularities of the beach wrack deposits, the complexity and costs of transport and storage, and the lack of customer awareness of the final products all make this business model difficult to replicate. Ideally, if beach wrack were an economically sustainable resource, the beach managers could charge the company for it. However, the limited financial value that can be extracted currently results in zero interest from the buyers. Nonetheless, it is a proof of concept that could work elsewhere under favourable conditions. Unique business model canvases and an economic comparison for each use option, demonstrated within the CONTRA project, can be found in CONTRA-report Almqvist et al. (2021).

In the end, the optimal solution for the individual beach has to be identified by its manager, who has to scan the local area for possibilities and see what works best for the quantities and composition of beach wrack they face. It is beyond the scope of this report to provide a comprehensive overview for the entire BSR. However, we do wish to motivate managers to do their research and consider the various available options to achieve the most favourable financial, social and ecological outcomes.

8.4 Operating within the Legal Framework

What managers are allowed to do is subject to various local, regional, national and European legal acts, depending on the political entity they are operating in. An overview of the responsible national authorities and relevant legal acts has been created as a separate CONTRA output – legal aspect document Armknecht et al. 2021. Our Estonian partners have also created a detailed overview of the Estonian legal framework (Consultare OÜ 2021). A comprehensive overview of all relevant legal acts for each BSR managed beach is beyond the scope of this report. However, we can list and discuss some similarities, overlaps and regular complaints expressed by the beach managers we surveyed.

Beach management is regulated in several legislative acts of the European Union. One of these acts is the Directive 2006/7/EC on the quality of bathing water. It contains no specific clauses regarding beach wrack. The closest it comes to addressing it is in Article 9 (Other parameters), stating:

1 *When the bathing water profile indicates a tendency for proliferation of macro-algae and/or marine phytoplankton, investigations shall be undertaken to determine their acceptability and health risks and adequate management measures shall be taken, including information to the public.*
2 *Bathing waters shall be inspected visually for pollution such as tarry residues, glass, plastic, rubber or any other waste. When such pollution is found, adequate management measures shall be taken, including, if necessary, information to the public."*

From a legal standpoint, it is questionable as to how a directive on water quality can be taken as a legal basis for managing beach wrack, which is specifically the material that lands on the beach, outside of the bathing water. Nevertheless, it is quoted by multiple surveyed managers for having an impact on their beach wrack management decisions.

The legal framework of the EU-wide Natura 2000 nature protection areas network is generally designed to forbid or discourage human intervention in the area. Human activities to be avoided range from settlement and construction to military, industrial and tourism use. In general, such protected areas and tourist beaches located within them should strive to leave nature in place as much as possible rather than cater to the expectations of (some) groups of tourists. Here is an excerpt from the Guidelines for the establishment of the Natura 2000 network in the marine environment (EC, 2007): "*More than 200 million tourists per year visit the European coasts (most of them the Mediterranean Sea), leading to huge and often uncontrolled development of recreational activities, mainly in coastal areas and shallow water, in particular during summer. Overexploitation by tourists of natural, well-conserved sites constitutes a real problem in some coastal plains by their action of trampling, noise, lighting, etc., or more specific issues, such as disturbing turtle nests due to off-road 4x4 vehicles …. In the marine environment, the main problems are the destruction of intertidal and shallow subtidal bottoms, and the presence of divers at unsustainable levels, causing erosion of sensitive ecosystems, such as coral reefs, or the modification of fish behaviour due to feeding practices*."

We were unable to find specific provisions on beach wrack in the Natura 2000 guidelines. This implies that there is no obligation in the criteria to automatically and periodically remove beach wrack from tourist beaches within Natura 2000 protected areas. Instead, the decision-making process would ideally be more holistic and take into account that all tourist (and other human) activities in such protected areas should be dissuaded in the first place. Indeed, the latest Habitats Directive, commonly alluded to by the Natura 2000 network, specifically designates the drift line as a habitat to be protected, implying that no beach management should take place there. Furthermore, CONTRA researchers informally express concerns about a lack of appropriate monitoring, infrequent reviews of the guidelines, and sanctioning.

Beach managers have expressed a desire for the legal frameworks to evolve in a sense to allow them the flexibility to adopt the best suitable reuse option. Even though beach wrack can in some cases have environmentally harmful components, these can and should be sorted out during the collection phase. This should not be a blank legal obligation to dispose of all beach wrack as a waste product. Direct use of beach wrack for coastal protection, public-private cooperation for removal, processing as well as further research should be legally allowed and, when possible, stimulated.

To summarise, for many aspects of beach wrack management, there is no single, uniform management guideline or legal practice across the BSR or even the European Union. Beach managers and responsible municipalities often struggle to find legal and affordable ways to manage beach wrack while meeting the (perceived) public demand for clean beaches. Often specifically due to legal hindrances, the potential for sustainable beach wrack



Figure 37 Beach wrack mound on Åhus beach, Sweden (© J.Almqvist)

management and reuse is far from being fully realised (Chubarenko 2020).

8.5 Overall Cost Factors and Cost Estimates

Information on quantities of beach wrack removed is sparse. There are very few records, and the surveyed beach managers either did not have this data or were unwilling to disclose it. Over the past 10 years, there have only been a few national studies which help give us a general picture. In 2012, one such study looked at 15 beaches along the 720 km long German Baltic Sea coastline. It determined that an average of 269 kg of beach wrack plus sand per meter of beach was being removed annually. German spa authorities removed up to 1000 kg of beach wrack per meter beach line every year (Mossbauer et al. 2012). While the available figures give us an idea of the scope of the problem, the measurements are sporadic and there is still a need for a lot more of localized data, especially outside Germany.

The situation is almost identical with removal costs and other cost factors. Some national studies, such as the work done in the project POSIMA in Germany, estimated that municipalities are paying average of 38 € per meter of beach line (Mossbauer et al. 2012). However, the costs vary widely depending on factors such as the collection methods used, investment in machinery and personnel costs. The most recent available figures from CONTRA indicate that the cost for beach wrack removal for municipalities in the BSR ranges between 20 €–40 € per meter of beach line. The costs are lowest in Russia and the Baltic states whereas they are highest in Denmark and Sweden. The cost factors most commonly cited as most expensive at our survey sites were personnel costs, machinery hire and processing off beach (→ Figure 36).

8.6 Practical Socioeconomic Considerations

The following canvases display the summary of the socioeconomic data from our five case study sites in Germany, Denmark, Sweden, and Poland. The information is based on the management interviews we had in 2019 and categorized according to the driver-pressure-state-impact-response (DPSIR) framework. This method was selected to present the sequence of beach wrack management using an established analytical framework.

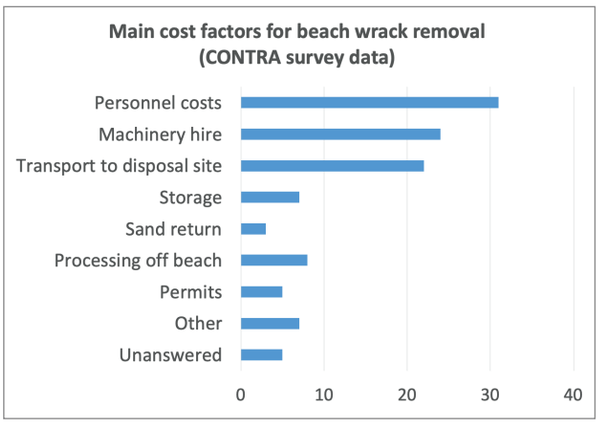


Figure 36 The cost factors that most commonly affect municipalities

Figure 37 Socioeconomic canvas for Køge, Denmark (Søndre Strand and Nordstranden)

	Driving forces of beach wrack management	Stakeholder interests pressuring the managers	Resulting state	The impacts of the management policies	The suggested responses by CONTRA
Tourism and recreation	Residents who live close to the beach, or use the beach Tourism revenue: 20 mio DKK/ 2.7 mio € directly attributed to beach; 150k yearly overnights in municipality; 60 % business tourism, 40 % vacation Cultural attractions (medieval town), recreational possibilities	Local residents have a lot to say about beach management. Tourist expectations of cleanliness and good bathing water quality are relatively low. Domestic DK tourists more tolerant. Most people don't think beach wrack is dirty. Public knowledge of beach wrack is relatively high. 1057 full time local jobs depend on tourism (3.7 % of all jobs)	Beach widened in 2015 Near daily manual and mechanical removal during the tourist season (1 May– 30 September); whole beach width cleaned. Beach wrack often simply pushed back into water upon landing or moved to other parts of beach;	Catering to local residents over tourists; other beaches in Copenhagen region are more famous/ have better facilities. Low beach wrack management costs Public satisfaction with beach cleaning routine very high; over 80 %	More cooperation between municipalities (build on working group activities) More knowledge on the impact of beach cleaning and climate change on local environment and ex. biodiversity. Dissemination of knowledge.
Health & Well Being	Litter dropped by tourists on beaches (high season) Decomposing beach wrack	Residents and tourists dislike smell when large amounts accumulate in swash zone.	Bathing water quality measured from 1 May–1 September Very low litter content in beach wrack itself.	No litter bins on beaches, only nearby Social responsibility for litter collection high Non-polluted beach wrack being removed	Explore possibility of decoupling beach cleaning for litter and that for beach wrack. More development of beach management technologies which will limit the amount of degradation of the beach wrack on the beach or in shallow waters.
Culture & Heritage	Strong DK traditional uses of beach wrack; roofing, agriculture, coastal protection	Some interest to keep old practices going remains, but most recycling industries have died off – subsidies needed	Cultural ties with beach wrack not being explored nor exploited.	Cultural identity and skills associated with beach wrack use have been lost.	Further development of feasible recycling options – increase private interest. Re-visit traditional uses. Explore subsidies. Local EIA of treatment would be beneficial.
Environment	Strong local awareness of sustainability and ecosystem importance of beach wrack.	Political interest in coastal protection (beach erosion, storm surges, climate change). Most local residents want it removed, but others think it is a natural part of the beach	Some spatial and temporal zoning in place, incl. beach cleaning limited to just 0.9 km out a total 1.5 km of beach and summer season collection	Impact (+ /-) of operations on eco-system services unknown. Whole beach is mechanically cleaned daily during summer – ecological impact unknown	Environmental Protection Law ambiguous – clarification needed. More research on the environment consequences of intensive cleaning routine and release of material back in water.

Figure 38 Socioeconomic canvas for Åhus near Kristianstad, Sweden (Täppetstranden)

	Driving forces of beach wrack management	Stakeholder interests pressuring the managers	Resulting state	The impacts of the management policies	The suggested responses by CONTRA
Tourism and recreation	Beach tourism worth ≈ €17 mio; Local jobs dependency. Täppetstranden is the only official tourist beach in area. Strong recreational focus, festivals and large sporting events	Tourist expect cleanliness and good bathing water quality. Reliant employers/ employees want strong business	Near daily manual and mechanical removal by local municipality during the season (April–September). Area up to 10 m from the waterline is cleaned. Dedicated beach cleaning machine.	Mixed structure residents vs domestic/foreign tourists; majority is domestic. Public satisfaction with beach cleaning routine very high; 86 % Y, 14 % somewhat, 0 % N	Further spatial zoning could be explored, i.e. small amounts of beach wrack left.
Health & Well Being	Past complaints of smell and aesthetics made by public.	Health and safety concerns (blue algae) Several reports made about illness in animals & people due to toxic blue algae associated with bathing Authorities aware of possible heavy metal contamination of beach wrack	Municipality monitors bacteria levels, takes samples at 19 spots Bathing water monitored 3–4 times per season, about every 30 days. Very low litter content in beach wrack	Blue algae risks are kept under control (warning signs/ bathing closures put in place if safety cannot be guaranteed)	Public information campaign about blue algae and its difference to beach wrack may be of value. Research /expert exhange on contamination levels.
Culture & Heritage	Strong history of beach wrack being used as a resource; agricultural uses, tobacco, fertilizer, e.g. for coastal forest	Authority reports that beach wrack amounts have been increasing over the past 10 years	Non-profit organisations clean the whole beach once per year	Large (3 week) sporting event dominates in summer (July) – but beach cleaning operations unaffected.	Further development of feasible recycling options – increase private interest. Clarity on the legal framework and effective communication of new policy (still in draft) about beach wrack and marine biomass needed
Environment	Above average local awareness of sustainability and ecosystem importance of beach wrack	Coastal protection – wind blown beach erosion is problematic. (Coastal pine forest established in 1800s)	Policy of spatial and temporal zoning: 2.5 km of a total 27.5 km cleaned. Sand is separated and left on the beach.	The immediate effects of beach grooming on beach erosion are ameliorated.	More research on the environmental impact of beach wrack management required. Broader stakeholder exchange. Increase awareness of beach wrack as a resource at local authority level.

Figure 39 Socioeconomic canvas for Puck, Poland (Puck city beach)

	Driving forces of beach wrack management	Stakeholder interests pressuring the managers	Resulting state	The impacts of the management policies	The suggested responses by CONTRA
Tourism and recreation	Beach tourism accounts for 10–15 % of tourist revenue.	Nearby tri-city area (Gdansk, Gdynia, Sopot) with over 1 million people. High domestic tourism. Tourist expectations of cleanliness, water quality also includes a beach free of beach wrack; conflation of beach litter and beach wrack Reliant employers/ employees want strong business	On demand manual and mechanical removal during the season (1 May– 30 September) 0–5 m from the waterline is cleared by hand or mechanical means, then temporally stored	Public satisfaction with beach cleaning routine ok; 53 % Y, 41 % somewhat, 6 % N	Choices are political and to be made by elected officials/appointed experts
Health & Well Being	Periodically there are reports of the smell and aesthetics of beach wrack. Touristic litter on beach problematic over summer period. Occasional blooms of cyanobacteria	Health and safety concerns of public (cyanobacteria). 5 warnings in 2018. The public has a poor understanding of the difference between beach wrack and litter; largely negative perception of beach wrack as a result	Monthly bathing water quality monitoring during the season by the state inspectorate	Blue algae risks are kept under control; black flag is displayed when	More distinction made between beach litter (plazowy odpad) and kidzina (beach wrack) on the management level.
Culture & Heritage	Cultural events, yearly celebrations, historic centre, religious tourism all boost cultural tourism	Authority reports that beach wrack amounts have remained the same over the past 10 years (Historical beach wrack treatment information lacking due to lost documentation post-WW2)	While cultural events and celebrations continue, knowledge of beach wrack and its management seems to have been largely lost due to tumultuous 20th century history	Poor understanding of definition and role of beach wrack by tourists not improved after visiting	Distinction and positioning of beach wrack should be made clearer and promote distinction from waste material..
Environment	Natura 2000 protected area and Program for the Protection of the Puck Bay and the Hel Peninsula. In principle, there is an argument against removal.	Coastal protection (beach erosion, storm surges, climate change – rising sea levels)	Natura 2000 legal framework causes complex governance and difficulties in decision making. Policy of spatial & temporal zoning, litter separated but not sand; some beach wrack left on beach to decompose	Exploitation of sand from the Bay of Puck, used to stabilize the Hel Peninsula and restore campsite beaches.	Improved cooperation between local and regional governments, and other stakeholders.

Figure 40 Socioeconomic canvas for The Island of Poel, Germany (Timmendorfer Strand and Schwarzer Busch)

	Driving forces of beach wrack management	Stakeholder interests pressuring the managers	Resulting state	The impacts of the management policies	The suggested responses by CONTRA
Tourism and recreation	Tourism revenue 770k € generated annually from "Kurtaxe" (spa tax) alone	Tourist expectations of cleanliness and good bathing water quality (Kurtaxe – payment asked of beach users, clean beach provided in return) Reliant employers/ employees want strong business. Local wages dependent on beach tourism: resort administration, tourist accommodations, souvenir shops, retail, lifeguards	Near daily mechanical removal during the season (1 May– 30 September) Public satisfaction relatively high (70 % Y, 0 % N)	Tourists desiring beach wrack free beaches continue to be drawn; cleaning made more responsive since social media boom	Political decision to be made by the beach manager on what tourists to cater to More info required on residents' views
Health & Well Being	Blue algae (vibrios) problematic during warm summers	Health and safety concerns (blue algae, vibrios). Sporadic public complaints about smell (moved online). Local authority feel driven to avoid negative press/ reviews.	Bathing water quality is regularly checked.	Algae problem is kept under control	Policy optimal under available data
Culture & Heritage	Cultural identity with beach wrack use for animal feed, mattress filling. Beach wrack amounts have increased over past 10 years	No data on local community lobbying for a particular use is available	Partnership with Hanseatische Umwelt, local private fertilizer company, removing the beach wrack at municipality's expense	Beach wrack is processed into sustainable outputs, such as fertilizer; municipality chooses to do so despite paying for it	Policy optimal under available data
Environment	Natura 2000 protected area; argument against removal/interference in general	Coastal protection (beach erosion, storm surges, climate change – rising sea levels)	Policy of spatial and temporal zoning, rotating the managed and unmanaged sections of beach on yearly basis	Impact to the beach ecosystem is reduced	Policy optimal under available data

Figure 41 Socioeconomic canvas for Juliusruh-Breege, Island of Rügen, Germany (Juliusruh beach)

	Driving forces of beach wrack management	Stakeholder interests pressuring the managers	Resulting state	The impacts of the management policies	The suggested responses by CONTRA
Tourism and recreation	Tourism revenue important for local economy 7.2 million yearly overnights on island of Rügen, Juliusruh is longest beach Spa tax exists but revenue unknown. On other such surveyed German beaches, removal frequency generally higher	Tourist expectations of cleanliness and good bathing water quality Reliant employers /employees want strong and consistent business.	Mechanical removal on demand during season (May–September) with machines otherwise used for road and tree maintenance, limiting effectiveness. Most beach wrack is stored on unmanaged beach section (8.5 km total/1.5 km managed). Around 30 thousand m^3 of beach wrack lands per year. Beach is cleaned in evening and early morning to avoid disturbing tourists. Public satisfaction with beach cleaning mixed (45 % Y, 45 % N)	Policy caters to users who prefer more removal. Storing beach wrack on unmanaged section saves costs and is better for beach integrity. No rotation reported between managed and unmanaged sections.	Better surveying of possible reuse options, cooperation options with private companies, other municipalities for storage Adopting a cost effective, scalable and legally approvable method for reusing beach wrack, such as biochar
Health & Well Being	Health and safety concerns Beach wrack is composed of a specific particulate matter, which turns very gooey and with a strong smell while decomposing	Tourists find gooey texture and intense smells particularly displeasing. Surveyed residents see it as belonging to the beach	Once beach wrack lands, it is generally an unusually displeasing factor on the beach due to texture and smell. The texture also makes it difficult to collect – algae collection and transport is biggest cost factor. Municipality evaluates removal need on case by case basis.	Direct health and safety concerns are taken care of. Decomposition on unmanaged section of beach in dry state	Improving collection methods to make removal more efficient and enable economically feasible processing and reuse
Culture & Heritage	Cultural causes – local identity and heritage	Residents see beach wrack as a natural component of the beach and the beach as a distinctive marker of local and regional identity	Beach wrack is removed with few other considerations in mind beyond catering to tourists and other beach users who prefer removal. Sand is separated on site and left on beach	Beach wrack is no longer perceived as a natural part of the beach, pristine beaches with no beach wrack and compacted sand become part of identity	Improve interaction with local stakeholders, experts and NGOs who push for a more balanced, holistic and inclusive view of beach wrack management
Environment	Secondary force: Coastal protection concerns No specific issue known/reported	Existential social, environmental and economic concerns about preserving the beach in its current state	Policy of spatial and temporal zoning in place. No dunes. Extra cleanings at season start/ before special events.	The short-term negative effects of beach grooming on the environment are ameliorated.	Policies generally optimal under available data; more environmental research required

The canvases could be considered a useful illustration of the different dynamics that go into play at the various case study sites. There are some parallels common to all, including the importance of tourism revenue and a general concern for tourist health and safety. However, depending on the beach, even the level of prioritization of tourists can vary, as seen in Køge. The specific concerns vary depending on the composition and amounts of beach wrack. Several sites can be lauded for a more proactive approach as regards the provision of information to tourists, stakeholder involvement, monitoring of health and safety criteria and the use of beach wrack after collection.

8.7 Summary

The average findings for each parameter of the DPSIR framework according to the relevant sections are summarised in the canvas below.

With the importance of beach wrack as described in mind, it is concerning that, in some interviewed municipalities, the conversation about sustainable beach wrack treatment has not even started. This is coming at a time when the prolongation of the main tourist seasons is resulting in an increased (perceived) pressure to groom the beaches longer (Mossbauer et al. 2012). On one hand, some progressive local authorities are trying hard to independently find legal, affordable, and socially, environmentally and economically sustainable solutions. On the other, they are restricted by having limited resources, a lack of knowledge and a lack of cooperation from the authorities and various stakeholders. Discussions with beach managers have helped us identify a specific set of recurring local challenges hindering sustainable beach wrack management (see below):

To conclude, cleaning the managed beaches of beach wrack is only the beginning of an extensive recycling process chain. And it is here where municipalities would ideally employ solution-based approaches aiming for realistic, cost effective and locally sustainable use options. The political goal of making the economy more sustainable, the social pressure to diversify BSR coastal economies beyond tourism, and a growing consumer demand for natural raw materials makes the search for meaningful recycling paths of beach wrack ever more topical.

Challenges needing to be addressed on a local level

- Costs and cost factors of beach wrack management, specifically for municipalities in 'beach wrack hotspot' areas
- A confusing legal framework - particularly with respect to non-market reuse options on the beach for, e.g. coastal protection, and the waste classification
- A lack of local knowledge about the environmental pros and cons of beach wrack removal incl. contamination levels
- Time pressure relating to 1) public demand for its removal and 2) storage/degradation of beach wrack material for recycling.
- A lack of means to cooperate, both with neighbouring municipalities and with private recycling companies/industry
- Lack of knowledge about trends and climate change impacts on beach wrack quantities

Figure 42 Socio-economic considerations of BSR beach wrack management – overview of findings for all case study sites

	Driving forces of beach wrack management	Stakeholder interests pressuring the managers	Resulting state	The impacts of the management policies	The suggested responses by CONTRA
Tourism and recreation	Primary force: Tourism revenue	Tourist expectations of cleanliness and good bathing water quality Reliant employers wanting to keep their businesses going; employees want to stay employed	Removal during high tourist season regular/on demand for big beach wrack deposits Public satisfaction with beach cleaning relatively good	The existing visitor structure is reinforced (people who like their beaches beach wrack free tend to return, whereas visitors preferring more natural beaches choose non-managed destinations)	Better public opinion monitoring to measure general pool of people interested in given beach destination rather than depending on social media that amplifies negative voices N.B. Choices are political and to be made by elected officials/appointed experts
Health & Well Being	Secondary force: Health and safety concerns, including cyanobacteria, blue algae, vitrios	Tourist expectations of high health, safety and well-being standards during their stay	Bathing water quality is generally monitored during season (except RU). Sites with specific concerns monitor them and take action if needed	Health and safety risks are kept under control (warning signs/bathing closures put in place if safety cannot be guaranteed)	Implement monitoring where there is none; communicate the risks clearly, also to foreign tourists; appoint inspection responsibilities clearly between state/regional/ local level
Culture & Heritage	Secondary force: Cultural causes – local identity and heritage to be preserved through long-running beach wrack management policies	Above average local/ national awareness of sustainability and ecosystem importance of beach wrack in DK, SE; average in DE; below average in RU, PL	Per survey: Residents see beach wrack as mostly negative, visitors are more neutral	Cultural causes are rarely officially considered by beach wrack managers, who rarely distinguish between beach management and beach wrack management	More inclusive, holistic approach to be undertaken, discrete beach management and beach wrack policies and data collection and analysis, wider consideration of social and economic factors
Environment	Secondary force: Coastal protection concerns (beach erosion, storm surges, climate change – rising sea levels)	Existential social, environmental and economic concerns about preserving the beach in its current state	Most have policy of spatial and temporal zoning. Some coastal protection (dunes) considered or put in place	The short-term negative effects of beach grooming on the environment, such as beach erosion, are ameliorated.	Policies generally optimal under available data; some beaches still do not zone; more environmental research required; each case site is unique

9 Conclusion

This report has analysed the socioeconomic value, role and impact of beach wrack in Baltic Sea tourist resorts. It has pointed out that the main driver of economic activity is the sandy beaches that attract tourists. Managing beach wrack is an essential obligation for beach managers trying to accommodate their tourists, keeping them happy, healthy and safe as they generate income for a plethora of local businesses. CONTRA has reaffirmed that the pure economic value of beach wrack does not compare favourably to that of the sandy beach and the tourist activities dependent on it. Nevertheless, beach wrack management also affects the society and the environment, giving beach wrack social and environmental value. Some of these beach wrack management practices corroborate the positive aspects of removing it, others do the opposite. Due to the complexity and intermixing of these factors, it is difficult to provide broad recommendations on general best practices for all beach (wrack) managers. Doing so confidently would require complex and expensive calculations specifically tailored to each beach site. These would in the end only underpin what are, in essence, political decisions as to what – the society, the environment, or the economy – is to be favoured. In the end, what we hope to have achieved is to have pointed out the various factors at play. This includes the various aspects that merit consideration in beach wrack management decision making as well as the multiple traditional and modern ways to recycle the collected beach wrack. The aim is that the beach managers who have read this become better aware of the dynamics of beach ecosystems, that beach wrack management is a specific issue and that it comes with many challenges and opportunities. Perhaps some managers can readjust their beach management policies after taking into account one or more of these aspects and possibilities that they may not have considered previously.

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Ecological aspects of sustainable beach wrack management

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1 Introduction

Sandy coastlines and their associated dune systems are fragile environments which are faced by many threats and require conservation so that these areas could function ecologically and provide most for the species that rely on this ecosystem. Marine sandy beaches are also highly attractive to humans and the use of coastal areas has increased marginally in the last century, causing also intensified management of these sensitive areas. "Appropriate management and successful conservation can only be achieved if the complex ecology of sandy beach ecosystems is understood" (McLachlan & Defeo, 2018).

This report No 3.3 is the main output of the project CONTRA (2019–2021), which was fulfilled within the Interreg Baltic Sea Region Programme. The report was prepared within the Work Package 3 "Sustainability and ecological assessment" by experts from the CONTRA project partners. It represents the results obtained in the studied managed and unmanaged sandy beaches located in Germany, Denmark, Russia, Sweden, Estonia, and Poland. For more detailed overview on beach wrack ecology-related research carried out under the CONTRA project please see the respective CONTRA report Möller et al., 2021.

The report covers main ecological aspects related to beach wrack ecology and beach management with focus on sandy beaches. The managed beaches had to fill the following criterias: 1) used for recreational purposes, 2) with dominance of sandy sediments, and 3) from where beach wrack is removed on regular basis. The ecological aspects of beach wrack are described in chapter 3, including the seasonality in amounts and composition of beach wrack in selected managed and unmanaged beaches and fate of beach wrack on the natural beaches, shoreline residence time, aeolian dispersal and decomposition. We also highlight the presence of litter on the beaches and in the beach wrack. Different aspects of beach management such as noise pollution, disturbing wildlife, mechanical disturbance, compacting effects, and potential other effects related to beach cleaning are overviewed in chapter 4. In chapter 5 we slightly touch the theme of ecosystem services of managed sandy beaches and in which aspects the CONTRA case-studies relate to those. Suggestions for sustainable beach management based on research carried out under the CONTRA project are presented in chapter 6.

2 Study area

As an almost landlocked inland shallow sea, the Baltic Sea is exposed to particularly high loads of nutrients due to the many rivers flowing into it and the low exchange with other seas. Due to the increasing human settlement (on present day over 85 million people) of the catchment areas, this influence has increased over the centuries. Consequently, the Baltic Sea is facing several challenges that affect its ecosystem functioning, e.g. eutrophication, hazardous substances, non-indigenous species, seabed loss and disturbance, overfishing etc. Reducing eutrophication of the Baltic Sea is continuously one of the biggest challenges, it is being estimated that over 97 % of the Baltic Sea area suffers from eutrophication due to past and present excessive inputs of nitrogen and phosphorus. There has been decrease in the inputs of nitrogen and phosphorus to the Baltic Sea sub-basins over the years, but agriculture still plays the key role in nutrient pollution (Feistel et al., 2018, HELCOM, 2018a). Contamination with hazardous substances is another great concern – thousands of environmentally hazardous substances have been identified as potentially occurring in the Baltic Sea and up to one fifth of those is being monitored regularly. Among others, the contamination levels of mercury, polybrominated diphenyl ethers (PBDEs), and the radioactive isotope cesium-137 are particularly high (HELCOM, 2018b).

The focus within the CONTRA project is given to sandy beaches, which are already managed in touristic purposes and where by removing the beach wrack it would be possible to contribute into reducing the nutrient pollution. Overall, the total coastline length of the Baltic Sea is about 8000 km and it is highly heterogeneous, the most distinctive is the difference between north and south – the coasts of Sweden and Finland are highly fretted and generally

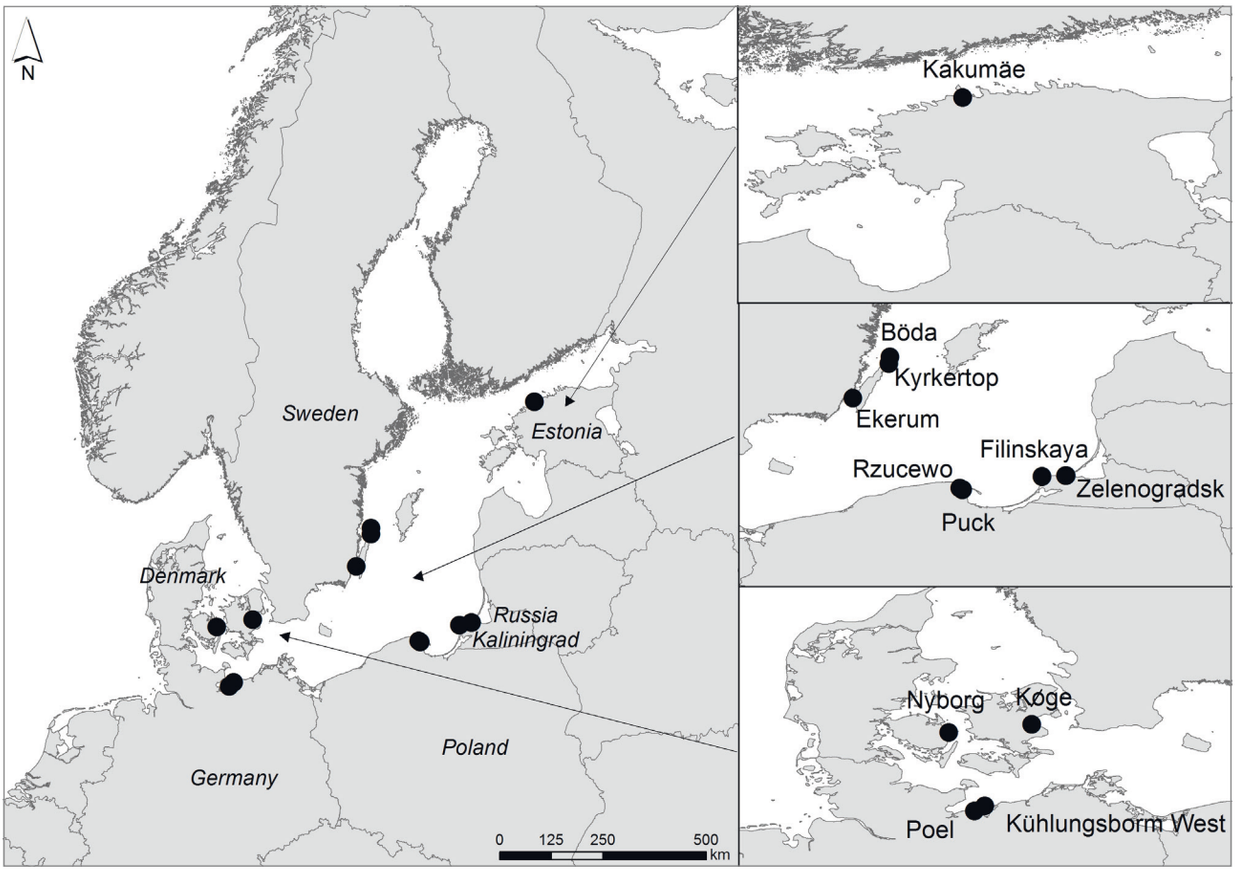


Figure 2.1. Map of the studied beaches.

rocky, whereas those of the southern Baltic are flat and rather featureless. The main coastal features in the Baltic Sea region are however sand or gravel spits with diversified dunes, cliffs cut in a variety of sediments and low-lying areas such as lagoons, wetlands and salt marshes (Łabuz, 2015). Within the CONTRA project different studies were carried out on the sandy beaches of the Baltic Sea within six countries: Denmark, Sweden, Germany, Poland, Russia (Kaliningrad) and Estonia. In every country at least one managed and one unmanaged beach was chosen for the comparison and to better highlight the impact of beach wrack removal on the ecosystem. In total, fieldwork was carried out in 23 beaches (beach areas) out of which 12 were managed and 11 represent the natural conditions (→ Figure 2.1).

On the countries level the share of sandy beaches and their management is very different (→ Table 2.1). The management of sandy beaches is of highest rate in Poland and Sweden, where about 25 % and 35 % of all sandy beach ecosystems are managed. However, this information on country level is in some cases very general or missing. For example for Denmark the share of managed beaches is currently not fully known and thus even rough estimations are hard to give. The total length of Danish coastline is about 8700 km and about 1800 km of it is protected by dikes or other permanent technical installations already (Danish Ministry of the Environment, 2005). Most of Danish coastline is sandy or covered with saltmarshes. Overall in Denmark there are 174 Blue Flag Beaches, which are either managed or monitored in regular basis. The total number of managed beaches is probably higher in Denmark.

Table 2.1. Indicative share of sandy beaches and the share of managed beaches per country. Managed beach hereby is considered as a beach, where beach wrack removal is a common practice. Information of managed beaches is very rough and based on various sources including personal communication with representatives from local municipalities.

Country	Total coastline, km	Sandy beaches, km	Managed beaches, km	Managed beaches, number
Estonia	3780	around 600 km	about 20	about 20
Russia (Kaliningrad)	145	most of 145 km	a few (varies from year to year)	a few (varies from year to year)
Poland	528	around 465 km	about 120	about 120
Germany	2582	around 1692 km	about 53	about 24
Denmark	8750	sandy beaches and saltmarshes prevail	at least 1800 km (coastal protection)	over 174*
Sweden	3218	around 350 km	about 100	about 25

3 Ecological aspects of beach wrack around the Baltic Sea

Sandy shores consist of three units – surf zones, beaches and dunes and this geomorphic system is also known as littoral active zone. Together beaches and dunes act as a protective buffer against storms and sea-level rise. The most characteristic feature of sandy shores is of course sand and its movement – wave- and wind-induced sand can be transported from up to 20 m depth from the seabed to the landward edge of the active dunes. As overviewed e.g. in McLachlan & Defeo (2018), two ecologically distinct systems are found in sandy shores – 1) a marine beach/surf zone ecosystem that is inhabited by marine biota and which is strongly affected by wave energy and 2) a terrestrial dune system that is inhabited by terrestrial plants and animals and is strongly influenced by wind energy. These systems are influenced by another in both directions.

In sheltered bays the openings of burrows may easily indicate the presence of infauna, however in exposed sandy beaches that are open to wave action the sand is in constant movement and the animals living in this area also need to be highly mobile in order to not to be swept away in the sea. Looking at a 2 m height these kinds of sandy beaches seem to be poor of life and they have been also described as marine deserts. Yet, when looked closer these beaches are also full of life, both microscopic and macroscopic. As in general beach sands have low organic contents, this environment depends largely on carryon from seawater. Input of dissolved organic matter depends on primary production level in the adjacent seawater and is carried into the interstitial system by water filtration. Particulate organic matter inputs include larger beach wrack quantities washed ashore which is then e.g. consumed by marine and terrestrial macrofauna and will enter the beach system and becomes available for animals living in the spaces between individual sand grains in the soil or aquatic sediments (for more detailed overview see e.g. McLachlan & Defeo, 2018).

In this chapter we provide a generalized overview of various ecological aspects related to sandy beach ecosystems including beach wrack amounts, beach-wrack associated species composition, seasonality, residence and decomposition, aeolian dispersal, nutrients, hazardous substances and litter. For methodology and more detailed information about the studies carried out under the CONTRA project please see the respective CONTRA-report Möller et al. (2021).

3.1 Beach wrack landings

Information regarding beach wrack landings across the Baltic Sea both on local and large scale is scarce. However, research carried out under the CONTRA project has given important baseline information for different areas and forms a solid base for further investigations. Based on primary predictive models, hot-spot areas of beach wrack accumulation (production up to 4000 g per m^2 per month) were noted in the Kattegat area, west and east coast of Sweden, all along the southern coast of Finland, west coast of Estonia and in Gdansk Bay (→ Figure 3.1.1, Kotta et al., 2020). Production hotspots were sporadically found also on the east coast of Finland, reaching the northernmost parts of the Bothnian Bay as well as on the shores of St. Petersburg. The remaining areas of the Baltic Sea were characterized by lower beach-cast production potential (approximately 0–1000 g per m^2 per month) (Kotta et al., 2020).

Beach wrack landings are highly seasonal – the largest amounts of beach wrack commonly reach the beaches in autumn at the end of vegetative season with autumn storms (→ Figure 3.1.2). However, it must be noted that the end of 2019 and winter 2020 were extremely warm and stormy and no ice or snow-cover formed during that period, this should be considered when interpreting the results presented here.

In our study from April 2019 to August 2020 the largest amounts were noted in Køge and Nyborg beaches, Denmark, where the beach wrack amount per 100 m long beach section were estimated as high as 140 m^3 (Køge, unmanaged), 124 m^3 (Nyborg, unmanaged) and 87 m^3 (Køge, managed) (→ Figure 3.1.2). In Rzuzewo, Poland the highest beach wrack accumulation was recorded in spring

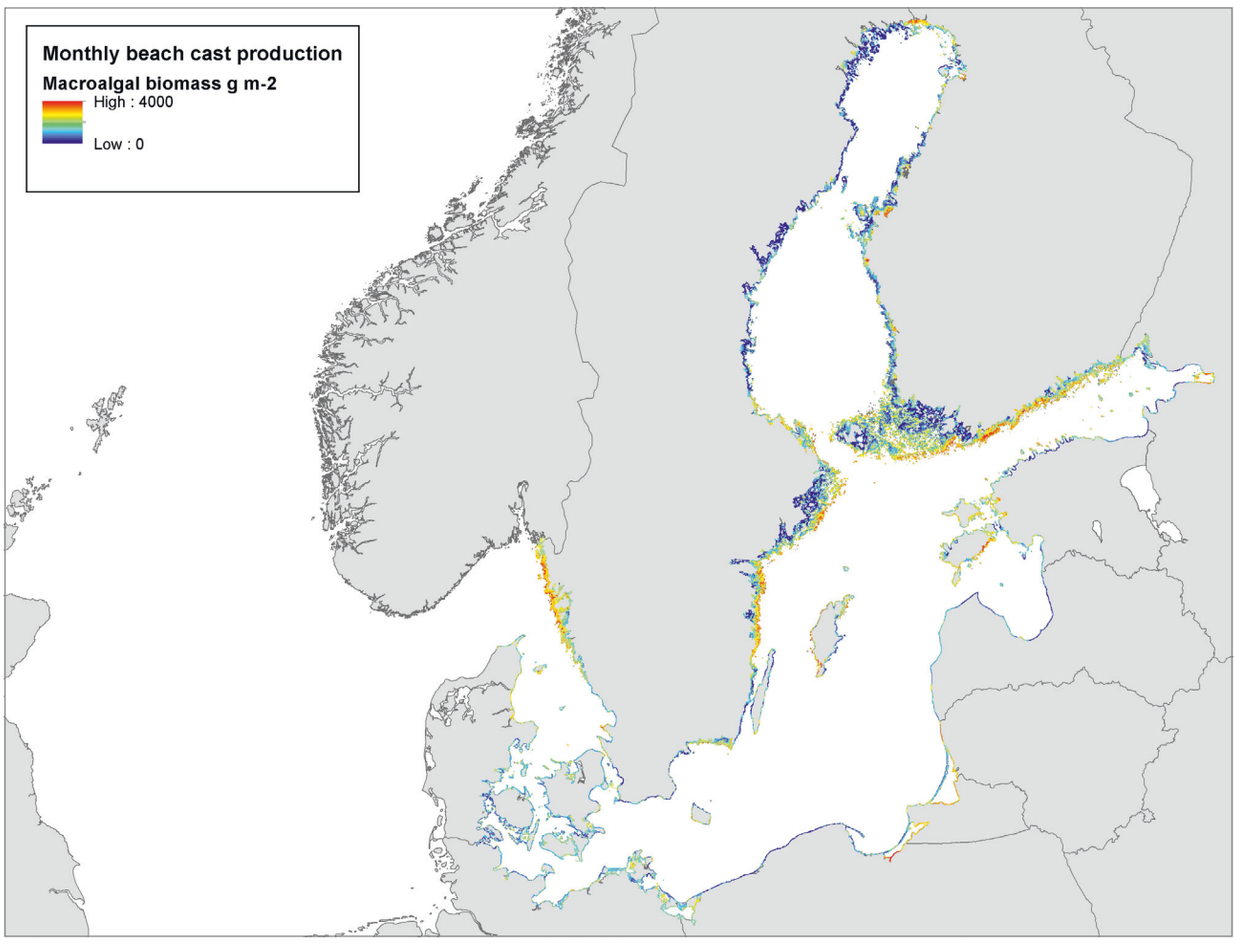


Figure 3.1.1. Monthly beach-cast production in [g m-2 dry weight] potential across the Baltic Sea in late autumn (October) (redrawn from Kotta et al., 2020).

2019 with the estimated amount for about 208 m³. In other areas the respective landings were usually less than 30 m³ of beach wrack per 100 m long beach section. Also in some beaches the beach wrack amounts were negligible throughout the year, e.g. Kühlungsborn West in Germany (the largest amount of beach wrack was determined once in early June 2019 with over 20 m³, otherwise the amounts stayed below 1 m³) and Puck beach in Poland.

The beach cast on the beach usually consists of several wrack lines depending mostly on the water level changes and wave activities (→ Figure 3.1.3, → 3.1.4, CONTRA-report Möller et al., 2021). It is common, that part of the algae biomass remains in the water. New wrack is usually the freshest algae near to the water as of old wrack line consists of already partly degraded and drier material. The exact beach wrack placement, it's amounts and residence time are important factors when it comes to e.g. estimating the emission of green house gases and leakage of nutrients and hazardous substances back to the water environment as these processes depend highly on the moisture content (e.g. Liu et al., 2019, see also → section 3.7 Hazardous substances).

In occasions when there are storms with parallel high tides and the water level reaches up to the foredune the beach wrack is placed far behind the usual wrack lines. When this happens, a clear distinction between old and new wrack is impossible. → Figure 3.1.4 shows the same beach at low water level and during a storm event which spreads the beach wrack all over the beach.

3.2 Beach wrack composition

The Baltic Sea offers habitat for about 530 macrophytes and algal species, for about 1900 invertebrate species, for about 240 fish species and 5 mammal species (HELCOM, 2012). However, finding all 530 algal species in one beach of the Baltic Sea is not possible as the beach wrack composition is most dependent on nearby prevailing marine benthic habitat types and dominating algae

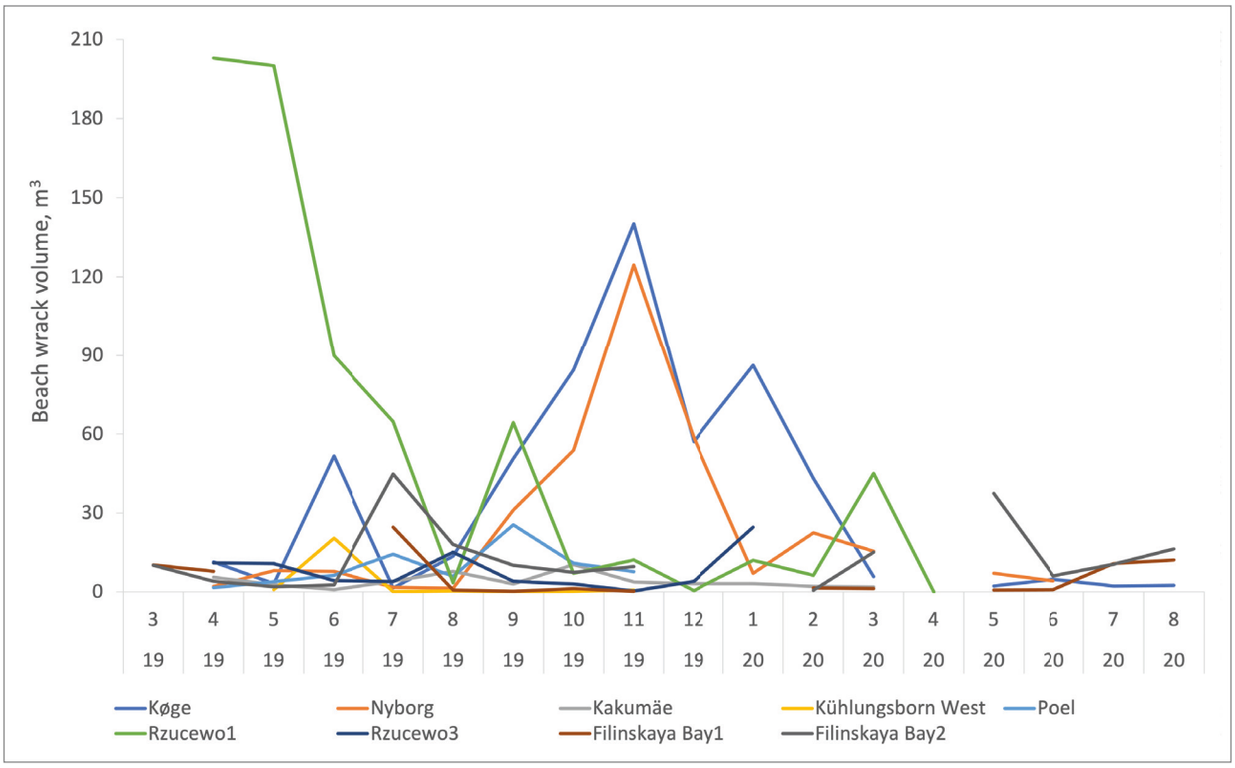


Figure 3.1.2. Beach wrack amounts (wet material, volume, m³) in studied unmanaged beaches in the period from April 2019-August 2020. The amounts are presented per a 100 m long beach section.

and macrophytes (e.g. Torn et al., 2015). But with greater storms and intensified water activity the material can be carried to the beaches also from rather remote areas. In general terms, compliance between beach wrack accumulation and submerged vegetation is hydrodynamically possible in case the alongshore currents are weak and the material on the beach originates from the adjacent sea areas. Higher wave events have a significant effect on the thickness and the amount of the beach wrack, no significant influence on the species number has been noted (Suursaar et al., 2014).

Based on estimations from studied beaches on a yearly basis, the main components of beach wrack were angiosperms and red algal species (→ Figure 3.2.1). In sheltered bays there is often an increased proportion of terrestrial plant material, unidentified or rotten wrack, and fauna. In the western Baltic Sea region angiosperms like eelgrass dominate the biomass, while dominance of red and brown algae (Rhodophyceae and Phaeophyceae) was observed within the eastern regions of the Baltic Sea (→ Figure 3.2.1).

Seasonality and species composition of beach wrack are closely related to the species annual life cycle. For example, eelgrass *Zostera marina* was found in particularly high biomasses within the autumn, reflecting the autumn storms where it is ripped off extensively and flushed on land.

More detailed beach wrack analysis was conducted at the beaches of Russia, Estonia and Poland. On the beaches of Kaliningrad Oblast, Russia in total 14 taxa of macroalgae and seagrasses were registered. Excluding the sand (which was on average 39 % of wet weight of beach wrack samples), the biomass of macroalgae was on average 95 %. Beach wrack with *Furcellaria lumbricalis* often contained some number of epiphytic organisms (*Mytilus edulis, Amphibalanus improvisus*, Bryozoa).The biomass of *Mytilus edulis* was comparable to that of algae occasionally. Old beach wrack sometimes contained large numbers of larvae and imago of Diptera in the summer period, but their biomass was not significant.

In Kakumäe beach in a one year period in total 131 taxa were described within the beach wrack, including 74 faunal and 57 floral species. In terms of origin, land-based fauna and sea-based flora dominated the beach wrack (40 and 39 taxa, respectively). In total 34 marine faunal species and remains of 18 terrestrial floral species were determined. In addition to the natural part of the beach wrack it can also contain artificial items such as litter (for more details see → chapter 3.8).

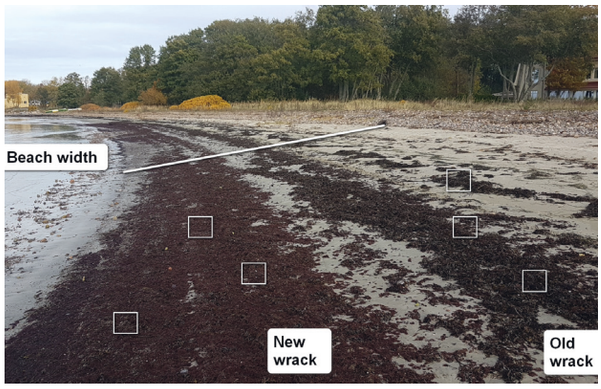


Figure 3.1.3. Beach wrack lines on the beach. Squares indicate the sampling methodology for species composition, 3 replicative samples (20 x 20 cm) were collected both from new and old wrack line. Beach wrack coverage and volume were estimated from the water's edge to the back of the beach (beach width) along the length of the 100 m long sample unit (Kakumäe beach, 15 Oct 2019, T. Möller).



Figure 3.1.4. Beach wrack lines at the beach "Am schwarzen Busch" in Poel, Germany. The upper picture illustrates very low water levels during Summer in July, second picture shows the same section during an autumn storm event in October. In the second picture much of the beach wrack is floating in the shallow water, being washed ashore and carted off in an almost minutely repeated manner (Poel beach, 01 July 2019 & 14 Oct 2019, P-K. Schätzle).

In Kakumäe Bay, Estonia, altogether 40 different terrestrial macrofauna taxa were found inhabiting the older beach wrack. Overall, representatives of Mollusca and Arthropoda were found in the samples. The molluscs were represented by species of the family Planorbidae (ramshorn snails), which are typical aquatic inhabitants among aquatic pulmonate gastropod molluscs, all other species were representatives of the phylum Arthropoda – crustaceans, arachnids and insects. Among these some species are most typical to this biota, e.g. springtails (Cl. Entognatha, Subcl. Collembola), *Saldula pallipes* (a species of shore bug in the family Saldidae), some species from genus *Sigara* (a genus of water boatmen in the family Corixidae), genus *Cercyon* with species *C. sylvestris, C. haemorrhoidalis, C. marinus, C. littoralis* (belongs to water scavenger beetles Hydrophilidae). Among Diptera many larval stages of the gnatmidge (Nematocera) and flie (Brachycera) species were found. Chironomidae can be found in almost any aquatic or semiaquatic habitat, many species in the genus are marine and are found in the intertidal zone of seashores. The share of occasional guests in beach wrack was also quite high which may be also related to the presence of terrestrial vegetation in old wrack line. Some beetle species that accidentally entered this habitat are for example ladybirds *Semiadalia notate, Coccinella septempunctata, Psyllobora vigintiduopunctata*, death-watch beetle *Ernobius abietinus*, barley flea beetle *Phyllotreta vittula*, weevil *Ceutorhynchus pallidactylus* and pea leaf weevil *Sitona lineatus*. Other occasional guests were: Psocoptera, Aphidodea, Homoptera and Neuroptera (*Chrysoperla carnea, Hemerobius lutenscens*).

Dominant floral species in beach wrack in Puck Bay (Poland) were *Zostera marina, Potamogeton pectinatus* and *Pylaiella* sp. In Rzucewo (Poland), beach wrack was dominated by *Potamogeton pectinatus, Zostera marina* and land plants (the stations are located close to overgrown dunes).

The marine macrofaunal composition was studied in more detail at two beaches of Poland: the Puck beach represents the managed and Rzucewo represents the unmanaged beach (see also CONTRA-report Möller et al., 2021). In both managed and unmanaged areas a total of 21 species or taxa belonging to the macrofauna were found, as well as epiphytic organisms *Amphibalanus improvisus* barnacles and 3 taxa that belong to the meiofauna – Nematoda, Turbellaria and Collembola. There were 20 taxa in total recorded in the unmanaged area, 7 of them were considered constant, although only 3 – Oligochaeta, Hydrobidae, Chironomidae – can be considered as dominant taxa in the overall abundance of the site's community. *Marenzellaria viridis, Limecola balthica* and *Gammarus* spp were constant species at the unmanaged site with relatively high abundance compared to the other taxa. In terms of biomass, representatives of Bivalvia and Gastropoda were dominant, due to the weighting of these individuals with shells.

In the case of meiofauna (organisms that can pass through a 1 mm mesh but will be retained by a 32

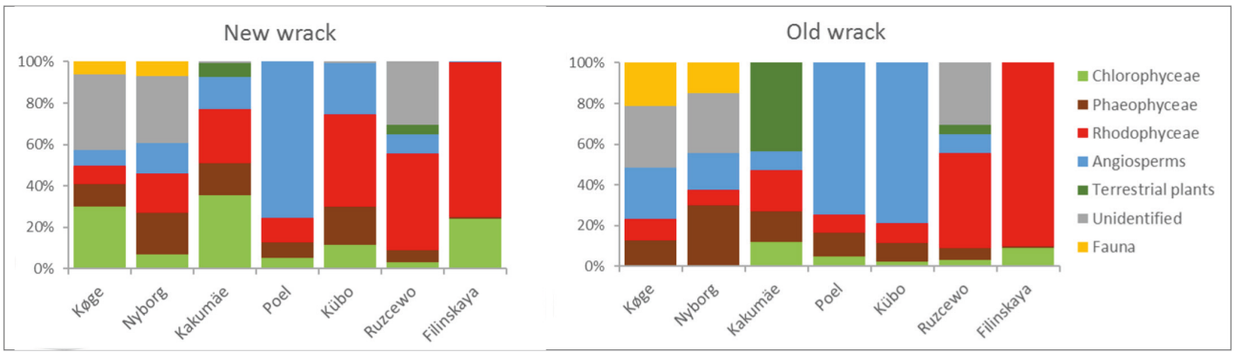


Figure 3.2.1. The average proportion of species composition within the wrack at unmanaged beaches within the study period April 2019–August 2020.

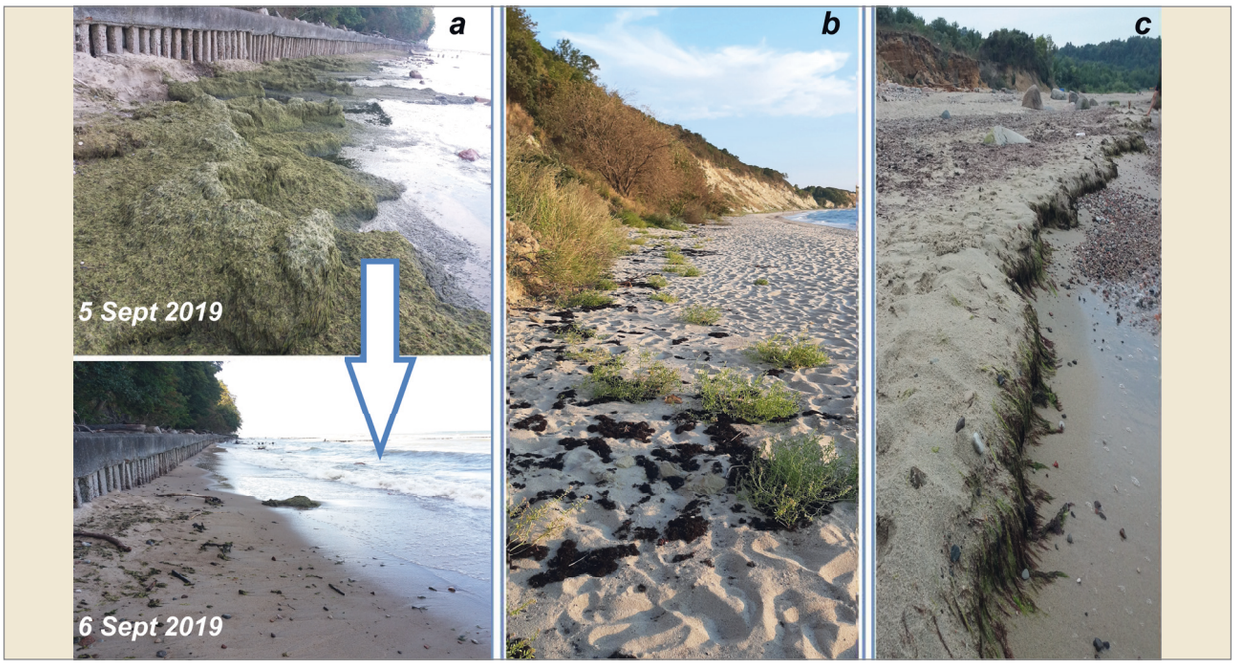


Figure 3.3.1. Beach wrack can undergo different transformation ways: flushing back to the sea (a), disperse inland the beach by wind and waves (b), covering under the thickness of sand (c) (J. Gorbunova).

µm mesh) fifteen higher taxa of meiofauna (one represented by larval stage – Copepoda *nauplii*) were recorded at both study areas in Poland. The most common taxa were Nematoda, Harpacticoida and Oligochaeta which were abundant at both sites, while Gastrotricha and Turbellaria were relatively abundant only at the managed beach in Puck. Generally the higher meiofauna densities were observed at the managed beach, however, during the winter months, January and February, higher total meiofauna abundance was found on the unmanaged beach, most likely indicating greater food availability from decaying organic debris. Additionally more favorable oxygen conditions may occur during the winter due to low water temperatures limiting the rate of decomposition and increasing the solubility of gases in water.

3.3 Residence time

Regrading beach wrack, besides the amount also residence time is an important factor for the terrestrial ecosystems functioning, resource characteristics, and management options. Variability in wrack supply on sandy beaches can be explained through interactions between wave exposure, hydrodynamic factors, coastal topography and seasonality (Barreiro et al., 2011, Suursaar et al., 2014).

Once on the beach, the beach wrack can either accumulate on the beach for a long time, it can be washed back to the sea or is covered with (thick) sand or small pebbles (potentially followed by flushing to the sea). Furthermore, dispersal by currents along the coastline and by wind to the inland occurs often in parallel. (→ Figure 3.3.1, → 3.3.2).

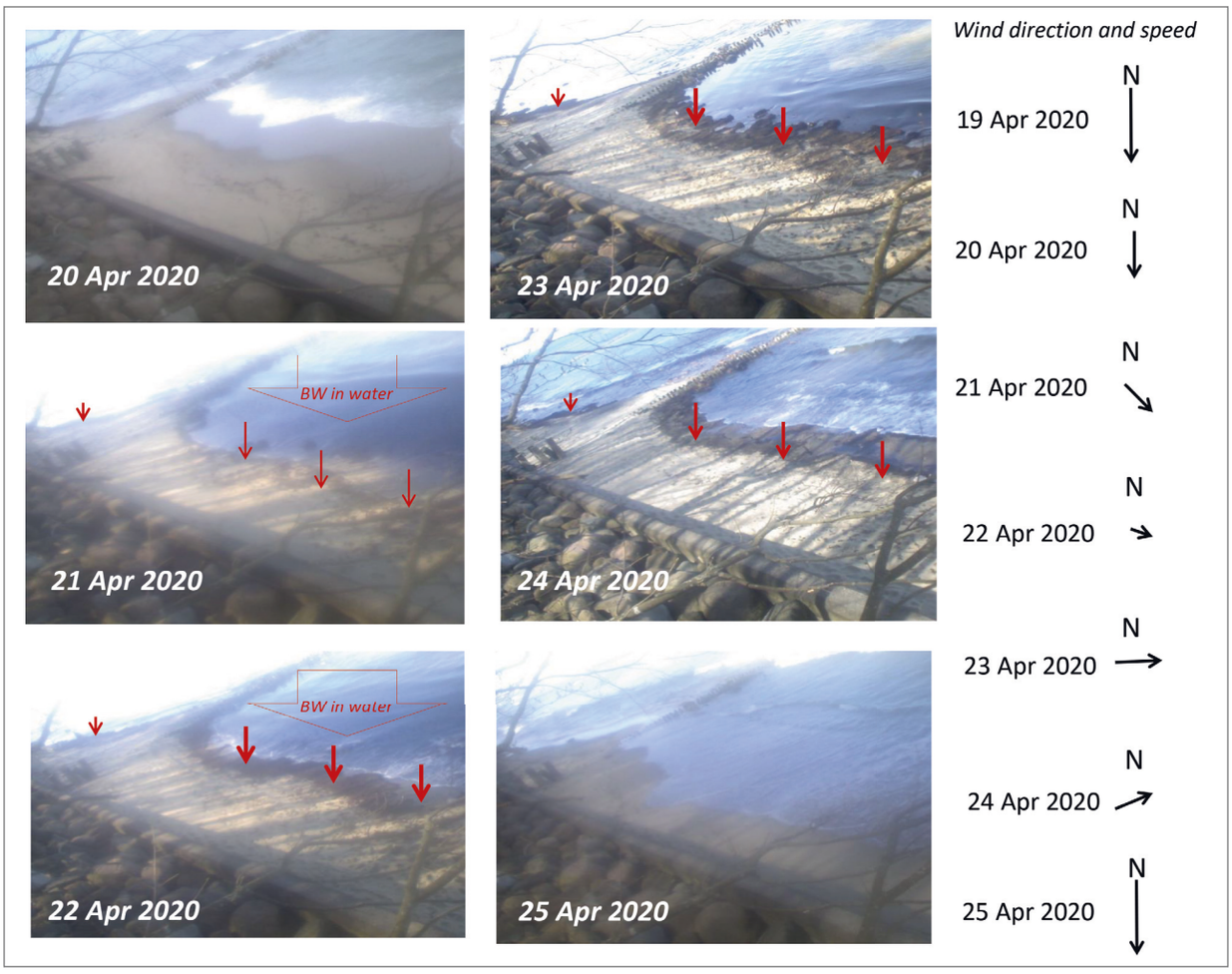


Figure 3.3.2. A typical example of beach wrack cast ashore and flushing due to the wind conditions (the western part of the Otradnoye beach, Russia, northern exposure of the coastline). The arrows indicate the direction and strength of the wind (the weather station is located at a distance of 5 km https://rp5.ru).

Our CONTRA studies confirmed that beach wrack residence time varies greatly between different beaches of the Baltic Sea. For example, a long-term presence of wrack is typical for Kakumäe beach (Estonia), which is a sheltered and shallow bay exposed to northern and northwestern winds. Wrack remained on the beach the whole time during the study period (336 days) in the unmanaged area and it was until being removed during the cleaning in the managed area (up to 214 days) (→ Figure 3.3.3). At the same time, beach wrack residence time was short at Otradnoye beach (Russia). The residence time ranged from 1 to 25 days and in average was less than 6 days (→ Figure 3.3.2, → 3.3.4). This short residence time is typical for most of the beaches of the Kaliningrad Oblast (Russia), which are all considered exposed beaches. In conclusion, beach wrack residence variations are related to hydrodynamic conditions, benthic habitats and characteristics of the coastline.

Consequently for planning management activities, it is necessary to consider peculiarities of the wrack residence time, thus short residence time can be a limiting factor for economically sufficient beach wrack harvesting. To improve efficiency, one solution could be the use of webcam observations on the potentially profitable seashore to coordinate the removal activities. At beaches with a long-term wrack residence, beach wrack is important for terrestrial ecosystems as well and all these different ecological aspects must be considered in planning management activities.

3.4 Decomposition of beach wrack

3.4.1 Natural decomposition of beach wrack in sheltered bays

As already mentioned in the previous sections, the effects of wind and storm waves differentiate input loads of beach wrack to beaches. On some occasions the beach wrack deposits cover beaches

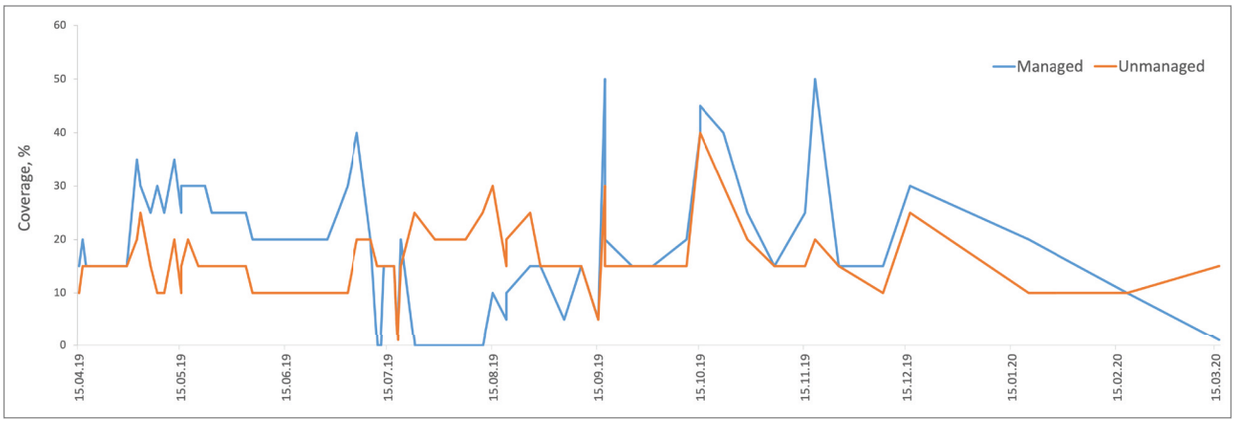


Figure 3.3.3. Beach wrack coverage (April 2019–March 2020) in Kakumäe Beach (Estonia) both in the unmanaged and managed area (100m long beach section). In 2019 the first beach wrack cleaning activity in managed beach section took place in the middle of June and overall there were 3–4 cleaning efforts.

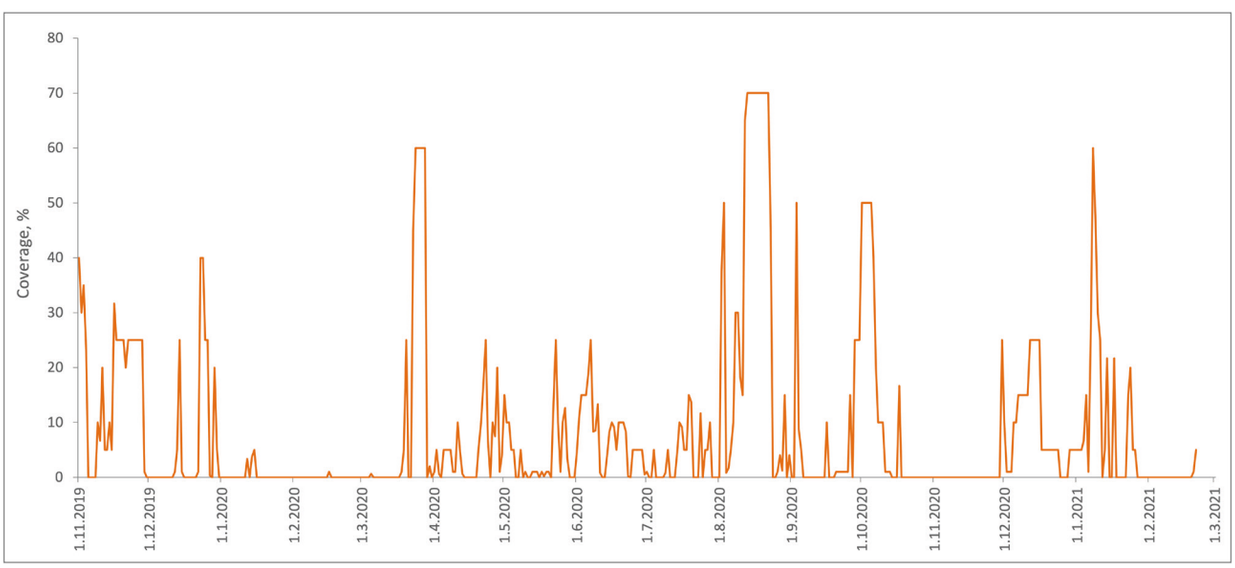


Figure 3.3.4. Beach wrack coverage (November 2019-February 2021) in Otradnoye Beach (Russia) (40 m long beach section, unmanaged).

in more than 1 m thick layer, providing important ecological and biogeochemical implications for the coastal ecosystem. Beach wrack contributes to coastal protection by reducing erosion of the coast from both the force of the sea and from sea-level rise caused by global warming, recycles nutrients to the coastal environment and dune vegetation, while providing habitats and food sources for marine and terrestrial biodiversity (Crawley et al., 2009; Mellbrand et al., 2011).

Within the CONTRA project a sheltered beach in western Öland, Sweden – Rälla beach – was studied in the means of natural decomposition process. The beach was mainly covered by decomposing algae (→ Figure 3.4.1, → 3.4.2). The most common species of macroalgae and seagrass that could be found within the beach wrack were: *Fucus vesiculosus, Fucus serratus, Furcellaria lumbricalis, Vertebrata fucoides, Ceramium tenuicorne, Rhodomela confervoides* and *Zostera marina*. The beach wrack deposits were mostly transported to the beach during winter storms. The Rälla beach was temporarily flooded by brackish seawater from the Baltic resulting in a relatively high concentration of salt in the soil, which also affects the composition of plant species. However, due to increased composition processes of beach wrack the soil is enriched with nutrients stimulating growth of vegetation that has high nutrient demand.

The areas closest to the sea were not colonized by plants and were only covered by layers of algae debris in different decomposition stages (→ Figure 3.4.3). It must be noted that this vegetation survey was carried out by the end of August 2020, and thus some of the species with earlier growth had already disappeared. The vegetation



Figure 3.4.1. Rälla beach in March 2020 (29 March 2020, Sachpazidou Varvara).



Figure 3.4.2. Rälla beach in July 2020 (5 July 2020, Sachpazidou Varvara).



Figure 3.4.3. The established vegetation on Rälla beach (Photo by Varvara Sachpazidou).

study did not include grass and *Carex* species, neither mosses nor algae.

The lower parts of the vegetated area of the beach were mainly covered by monocultures of *Atriplex littoralis* and *Chenopodium album* (→ Table 3.4.1). In the upper zones of the beach the substrate consisted of a more decomposed organic soil substrate and the species diversity was a bit higher. Here *Urtica dioica* was abundant, but also *Calystegia sepium, Lamium purpureum* and *Galeopsis tetrahit* were found. Also single species of *Achillea millefolium* and *Scorzoneroides autumnalis* and some individuals of *Salix repens* were recorded. In more moist parts *Phragmites australis* was abundant. At the edge of the forest Rälla Tall, in areas that normally were not flooded, adult species of *Quescus robur* and *Alnus glutinosa* were common, as well as some individuals of *Salix caprea*. Due to very robust and cosmopolitic species list we conclude that Rälla's vegetation is adapted to grow in extreme weather conditions and reflects the high nutrient supply within the beach area.

The amount of wrack accumulating on the Rälla beach varied across sites and seasons during the year 2020. We estimate that it will take a long time for this beach wrack landings to disappear and it must be pointed out, that it is a recurring phenomenon in recent years with increasing rates of

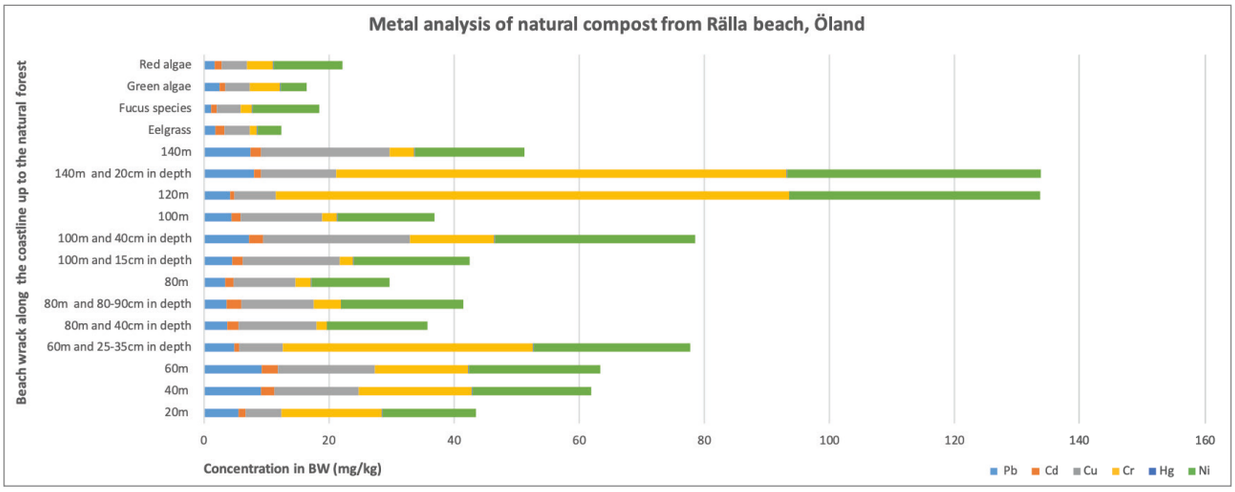


Figure 3.4.4. Heavy metal (Pb, Cd, Cu, Cr, Hg, Ni) distribution from the coastline up to the forest in Rälla beach (Öland, Sweden).

Table 3.4.1. List of species growing on the beach wrack piles in Öland, Sweden. The abundance was estimated accordingly: 1 – rare, 2 – frequent, 3 – abundant. Information regarding habitat and flowering is adapted from the University and Jepson Herbaria of the University of California database https://ucjeps.berkeley.edu/ (visited 03 May 2021).

Species	Abundance	Habitat	Flowering time
Atriplex littoralis	3	Sandy seashores, beach wrack piles	July–September
Chenopodium album	3	Waste grounds, roadsides	June–September
Alnus glutinosa	2	Seashores, nutrient-rich grounds, moist broadleaf woods	April
Lamium purpureum	2	Beach wrack piles, waste grounds, roadsides	May–October
Phragmites australis	2	Ditches, disturbed sites	April–October
Quercus robur	2	Mixed forests	June
Achillea millefolium	1	Meadows, waste grounds, shores	July–October
Calystegia sepium	1	Woodland borders, open floodplain areas along aquatic environments, waste grounds	May–August
Galeopsis tetrahit	1	Waste grounds, rocky outcrops	July–September
Rumex crispus	1	Shores, fields, waste grounds, roadsides	July–August
Rumex maritimus	1	Shores, muddy aquatic grounds, woodlands	June–September
Scorzoneroides autumnalis	1	Shores, rocky outcrops, roadsides, waste grounds	July–October
Salix caprea	1	Damp and rich coniferous forests, broadleaf woods, shores, roadsides	April–May
Salix repens	1	Sandy shores, sandy pine woodland	May
Sporgularia marina	1	Coastal beaches, wetlands	June–August
Tripleurospermum maritimum	1	Seashores, beach wrack piles, roadsides, waste grounds	June–September
Urtica dioica	1	Roadsides, waste grounds, shores, stream sides, broad-leaved forests	July–September

intensity. Ekerum´s inland forest which is extended to the Baltic Sea, forms in combination with strong winds, excess humidity, forest species communities and water regime, the Rälla beach and is subsequently a part of the coastal area. Therefore, Ekerum's upland forest community include the beach forest sandy soil "Rälla".

The depth profile of the Rälla beach wrack layer can reach 2 to 3 meters as the landing process has continued over 20 years. To determine the accuracy of the quantification of beach wrack and the relationship between depth and cover classes with biomass, compost/soil samples were taken along a 20 m transect from the coastline up to the natural forest (→ Figures 3.4.4). Evaluation of the samples was performed with regards to metal concentration (→ Figure 3.4.4, see → subchapter 3.7 and CONTRA-report Möller et al., 2021 for more details), moisture and organic content. Zinc concentration varied inbetween 115–290 mg/kg with lowest values observed near the waterline and highest values at 140 m from the water edge. Organic content showed the smallest variance, the observed values were inbetween 95–99 % and moisture content decreased gradually with increasing distance from the waterline (80 % of moisture content was noted near the waterline, 25 % was observed at 120 m distance from the waterline). The analysis package was

perfomed regarding Swedish legislation for compost. Based on the determined levels of heavy metals, the compost material in Rälla beach is suitable for use in growing edible crops.

3.4.2 Decomposition rate

Residence time and decomposition rate are strongly related and must be considered in beach wrack management activities. Marine macrophytes directly enhance abundances of sandy beach fauna through provision of food and habitat and therefore the residence time i.e. time for degradation process on the beaches is most important for the local faunal assemblage (e.g. Ince et al., 2007).

Under the CONTRA project the decomposition experiments were performed with species, which are characteristic of the study area. In Poland, wrack deposits on the Rzucewo beach are composed almost exclusively of the eelgrass *Zostera marina* and the filamentous algae *Pilayella* sp. or *Ectocarpus* sp., which are difficult to distinguish in the wrack. In Estonia, Kõiguste bay, both higher plants and perennial algae accompanied with filamentous algae were found in beach wrack. While the Baltic Sea hosts both attached and loose-lying form of *Furcellaria lumbricalis*, the attached form was used in this experiment.

Significant weight loss occurred within the first month when 14 to 85 % of initial dry weight was lost (→ Figures 3.4.5, → 3.4.6). After four months and more the changes in the remaining biomass were minor. Rapid decline of biomass of filamentous species during the first months was followed by a decrease of more than 90 %. More surprisingly, *F. lumbricalis* showed considerably high decomposition rate despite of relative sturdy thalli. In Estonia, *F. vesiculosus* was the most resistant to decay. *F. vesiculosus* lost 60 % of initial biomass during the year, while *F. lumbricalis* lost 99 % and *M. spicatum* lost 98 % (→ Figures 3.4.7, → 3.4.8).

In addition to morphological differences, the degradation time of different species was significantly affected by the placement of wrack on the shore. In general, degradation was faster in water compared to the placement of wrack above the sediment or buried in the sand (→ Figures 3.4.5, → 3.4.6). The decline of plant material buried in sand in driftline was faster compared to wrack buried in the sand near dunes. While the degradation of *Z. marina* submerged in water was similar to the degradation rate of filamentous algae, the species showed significantly higher resistance when was buried in the sand (→ Figure 3.4.5).

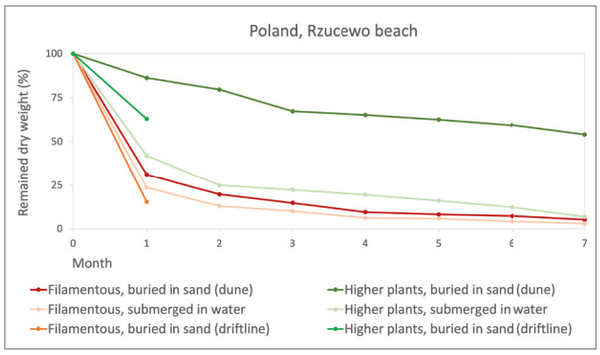


Figure 3.4.5. The average proportion of the remained initial dry weight of filamentous algae (*Pylaiella littoralis* and/or *Ectocarpus confervoides*) and higher plants (eelgrass *Zostera marina*) from July 2019 to February 2020.

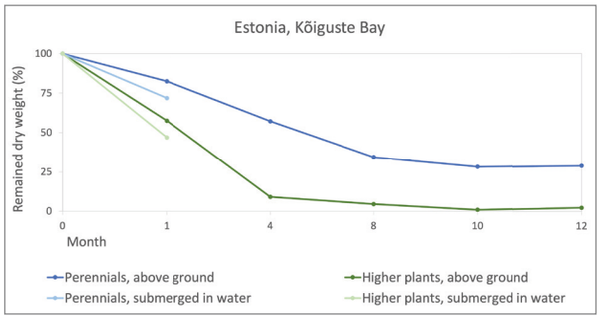


Figure 3.4.6. The average proportion of remained initial dry weight of perennials (mainly *Fucus vesiculosus* and *Furcellaria lumbrialis*) and higher plants (mainly *Myriophyllum spicatum*) from August 2019 to July 2020.

The mass loss of beach wrack in wet low-beach is considered predominantly affected by beach fauna, followed by loss from leaching while in the dry high-beach microbial respiration has higher importance (Jędrzejczak, 2002b). The study carried out in Germany refers that in a one-year period the eelgrass that is buried under sand shows very little signs of degradation. Similarly, previous studies have shown that degradation is greater on the surface compared to the buried organic material (e.g. Hackney, 1987).

The Baltic Sea is seasonally varying system, thus characterized by strong fluctuation in temperature, light and hydrodynamic conditions. The degradation of beach wrack is therefore strongly influenced by climatic and site-specific conditions. Consumption of beach wrack by grazers depends on the edibility of the wrack and the environmental conditions that affect both consumers and consumed materials. Both low and high temperatures drastically reduced the consumption of algal material. Decomposition of algae enhanced the consumption by microorganism, with maximum rates

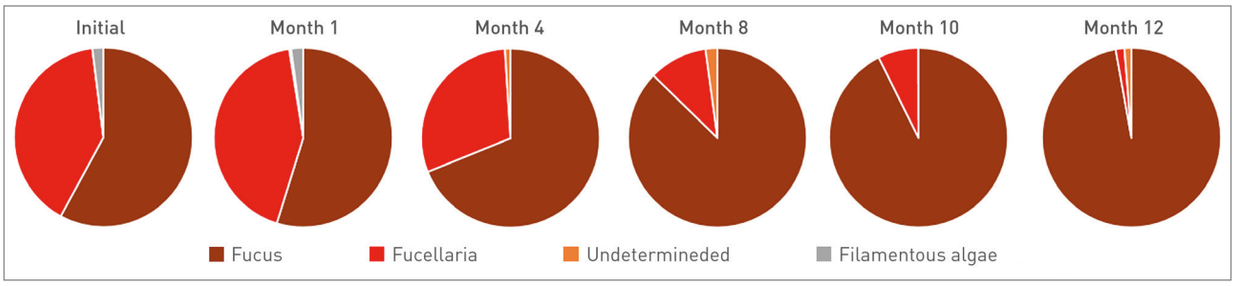


Figure 3.4.7. The average proportion of species groups in beach wrack (initially dominated by perennials *Fucus vesiculosus* and *Furcellaria lumbricalis*) used in degradation experiment carried out in Estonia.

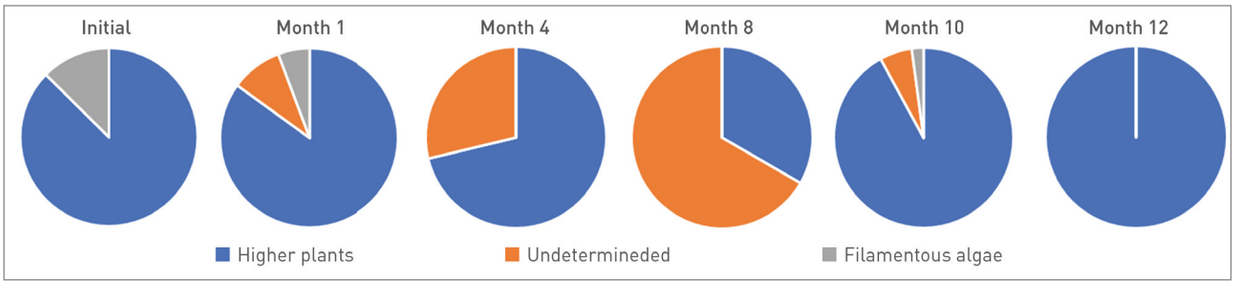


Figure 3.4.8. The average proportion of species groups in beach wrack (dominated by higher plant *Myriophyllum spicatum*) used in degradation experiment carried out in Estonia.

obtained when algae decayed in a wet environment (Lastra et al., 2015).

To summarize – the algal degradation process is more rapid in the water than in the coastal environment. It must be taken into account, that hereby the lower temperatures (experiments started in late summer) affect the long-term low degradation level, however it is noteworthy that most of the mass loss of different species took place within 4 months being the most significant for filamentous species.

3.4.3 Greenhouse gases emissions

The decaying beach wrack may contribute substantially to global greenhouse gas emissions (this report, Liu et al., 2019). E.g. beach wrack composed by *Zostera nigricaulis* and *Amphibolis antarctica* can be substantial source of CO_2, but not CH_4, during the decomposing process. In Liu et al., (2019) the observed biomass loss with coinciding CO_2 emissions followed a double exponential model (R2 > 0.92). The initial flux rate is usually high, most likely due to rapid leaching of labile compounds, followed by a decrease and stabilizing at < 3 µmol g^{-1} d^{-1} during the remaining decomposing period. Additionally, beach wrack can be cast high up on beaches and remain dry – in this case the seagrass-dominated beach wrack had 72 % lower emissions than wrack that was subjected to repeated wetting in the intertidal zone (Liu et al., 2019). This implies that relocation of seagrass wrack by coastal resource managers (e.g. from water's edge to drier dune areas) could help to reduce atmospheric CO_2 emissions. However, if the located wrack is accumulated in large piles, CO_2 emissions may be stimulated, since rainfall and high temperatures in summer may stimulate the degradation of this material (see below the → case in Køge, Denmark). On a global scale, it is estimated that the annual CO_2-C flux from seagrass ranges between 1.31 and 19.04 Tg C yr^{-1}, which is equivalent to annual emissions of 0.63–9.19 million Chinese citizens (→ Figure 3.4.9, Liu et al., 2019).

The green-house gas CH_4 has a 25 times greater green-house warming potential than CO_2 and in coastal ecosystems its emission depends on salinity level (0–35 psu) with the most intense CH_4 emission production at intermediate salinity levels (9–18 psu) (Misson et al., 2021). The CO_2 and CH_4 emissions in beach wrack are also dependent on species composition, water body residence time, wave action and residence time of beach wrack on the sand. For instance, annual and opportunistic species of macroalgae degrade faster than perennial macrophytes. A longer residence time and presence of macrophytes in the water body allows a higher rate of degradation compared to the beach wrack deposited in the sand. Intense wave action contributes to the fragmentation of the macrophytes tissues, which accelerate the rates of

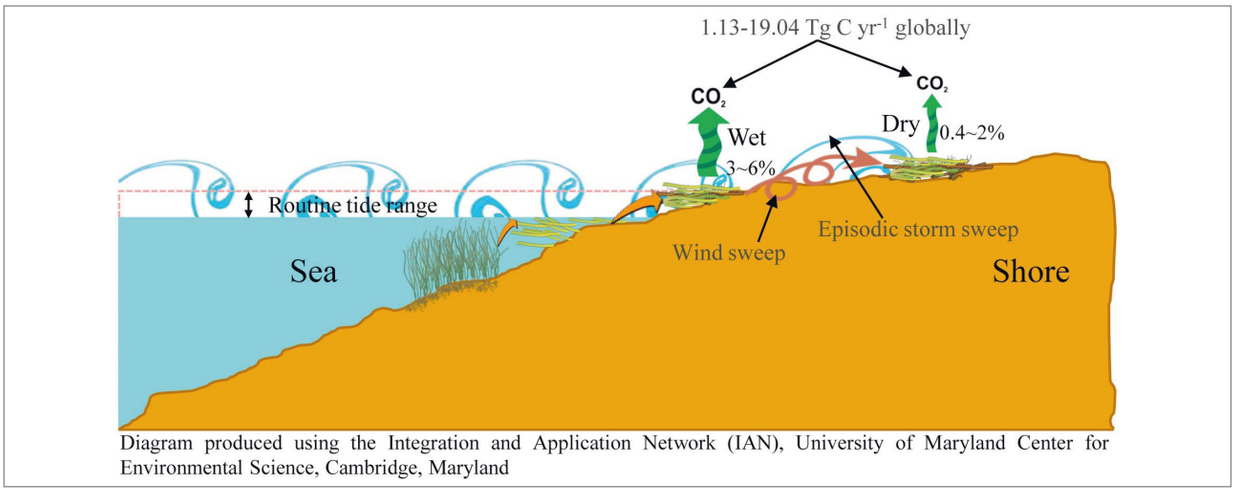


Figure 3.4.9. The schematic figure of green hose gases emission from the beach wrack (redrawn from Liu et al., 2019).

degradation and green-house gases emission.

In the Baltic Sea region the studies on green-house gases emission from beach wrack are currently rare. Under the CONTRA project these measurements were carried out monthly from July 2020 to January 2021 in a beach in Køge, Denmark. The efflux is expressed as mmol per m² per day. In Køge, beach wrack composes mainly of the eelgrass *Zostera marina* and the filamentous annual brown algae *Pylaiella* sp. and *Ectocarpus* sp. and the perennial brown algae *Fucus vesiculosus*.

Temporal variation and temperature-dependent emission of CO_2 is noted from the results (→ Figure 3.4.10). The high summer temperatures of 20 °C corresponds with high CO_2 emissions in August for especially Køge unmanaged beach. Measurements of lower emissions in January is in correspondence to lower temperatures. The CO_2 emission reached the highest rates in August in the new wrack and sand (9346–6722 mmol m^{-2} d^{-1}) in Køge unmanaged beach, followed by the pile of beach wrack (7131 mmol m^{-2} d^{-1}) in September on the managed beach. The air temperature was 20 °C and 15 °C for August and September, respectively.

The pile of beach wrack from the Køge managed site showed emission of CO_2. The pile was compiled in the back of the managed beach after cleaning in the summer months. Missing values corresponds to lacking of either new or old beach wrack or non-detectable emissions from the data points. Emission rates of CO_2 were generally higher ranging from 331 to 9346 mmol m^{-2} d^{-1} for all measured sites, i.e., new wrack, old wrack, sand and water than CH_4 (-3–109 mmol m^{-2} d^{-1}) (→ Figure 3.4.10). CH_4 and CO_2 showed temporal variation and temperature-dependent emissions. The emission of CH_4 was higher in summer months compared to the winter months. The CH_4 emission reached the highest rates in September in the water (109 mmol m^{-2} d^{-1}) in Køge managed beach, followed by new wrack emission rates in August in both managed and unmanaged beach (70–75 mmol m^{-2} d^{-1}) (→ Figure 3.4.10). Emissions of CH_4 in the water was always higher compared with the emissions from sand, new wrack and old wrack which was either not detectable or very low. The emissions of CH_4 were in general higher for the managed site in comparison with the

Table 3.4.2. Estimated total emission in CO_2 equivalents (tons) for 7 months measures of the green-house gases CO_2 and CH_4 in Køge managed and unmanaged beaches.

Køge Managed Beach	CO_2 equivalents (tons)
Sand	10.5
Water	14.3
New wrack	6.7
Old wrack	0.4
Pile	12.0
Total	43.9
Køge Unmanaged Beach	
Sand	2.1
Water	7.7
New wrack	9.7
Old wrack	2.7
Total	22.2

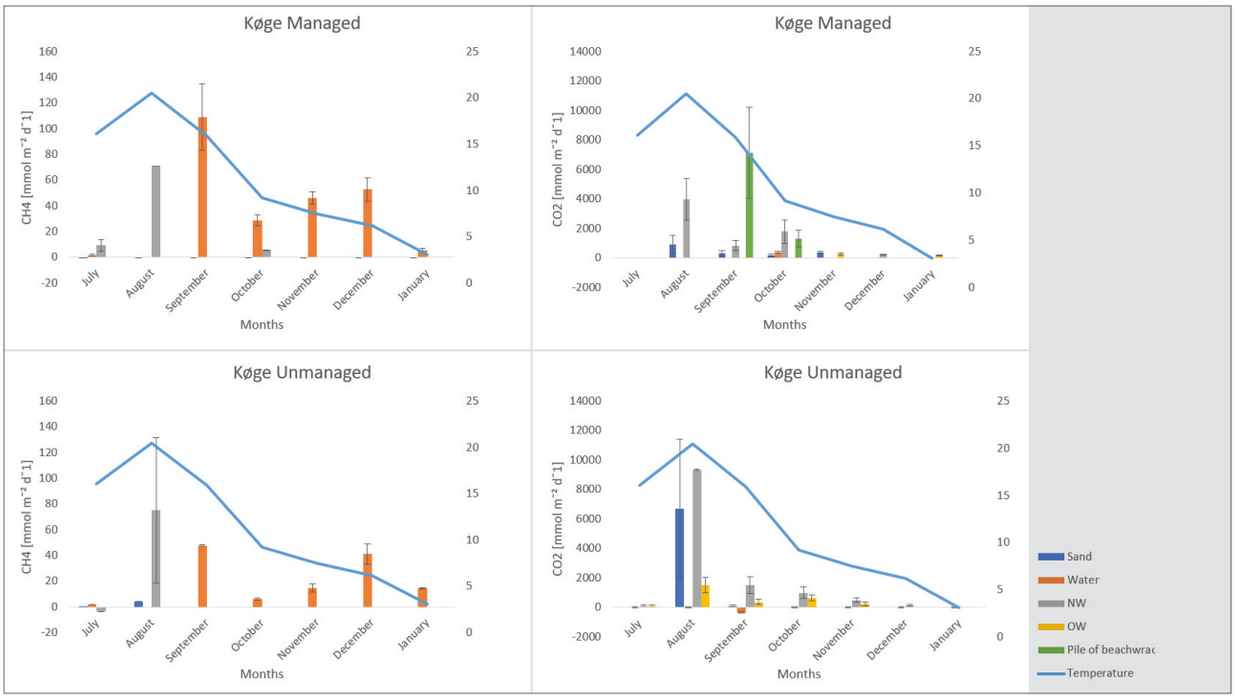


Figure 3.4.10. Monthly GHG emissions from July 2020 to January 2021 in the sand, new beach wrack (NW), old beach wrack (OW) and water in Køge (Denmark) managed and unmanaged beaches. The full line represents the average air temperature for the sampling day.

unmanaged site, especially for the water emission measurements. Uptake of CH_4 was observed only once during the sampling period (July sampling) for the new wrack on the unmanaged beach.

To make a conservative assessment of total green-house gases emissions, we converted CH_4 emissions to CO_2 equivalents based on 25-factor green-house warming potential and summed with the CO_2 missions and finally transformed the emissions to the corresponding area size of each beach and measured locations (new wrack, old wrack, sand, water). Køge managed beach has a total emission of 44 tons, with the largest contribution of water, sand and pile of accumulated beach wrack (~280 m³) (→ Table 3.4.2). The cleaning of the beach by tractors removing beach wrack by pushing it back to the water can explain the high emissions both in the water and in the sand. The tractors activity mixes the beach wrack in the sand causing higher fragmentation of the material, degradation and thus green-house gas emissions. This sand mixing effect is not observed in the unmanaged beach. In the unmanaged beach the newly deposited beach wrack had the highest emission which is explained by the level of moisture in the material (→ Table 3.4.2). For more precise calculations, a higher resolution of coverage areas of new wrack, old wrack, and also presence of macrophyte material in the water are needed.

The green house gas emission from the beach wrack is an important research field that needs more focus. This information is most valuable for developing present-day coastal carbon budgets to better understand and map changes in coastal development, beach management, general eutrophication, wrack accumulation, and climate, and the relationships between those. As Liu et al., 2019 proved, the location of the beach wrack with regard to moisture content is important as it is possible to reduce atmospheric CO_2 emissions e.g. by relocating beach wrack from water's edge to drier dune areas. At present day, relocating and piling up the beach wrack is a common practice in some beaches along the Baltic Sea. However, our study has shown that this material should not be compiled in large piles, since weather conditions such as rain and temperature may trigger organic degradation. Therefore, the relocation of beach wrack to drier dune areas in the Baltic Sea should consider this effect in the future management of beach wrack. More detailed studies regarding the emissions of green-house gases in different amounts of such beach wrack relocations are needed. The management practices, for example, the use of tractors and the transport of beach wrack back to the water may in some cases not be optimal when green-house emissions are considered.



Figure 3.5.1. Dense vegetation of the back of the beach accumulate some amount of beach wrack (photo: Julia Gorbunova).



Figure 3.5.2. The beach wrack in the vegetation of the back of the beach in the Filinskaya bay, 08.02.2020 (photo: Julia Gorbunova).

3.5 Aeolian dispersal

Many studies show the important role of marine beach wrack for beach ecosystem functioning (e.g. Polis & Hurd, 1996, Ince et al., 2007, Barreiro et al., 2013). The aeolian dispersal of sand and beached organic material is the most crucial process in the formation of dunes. The biomass thrown ashore is a pivotal fertilizer for dune vegetation in the process of coastal dune formation (Walter, 1975). Accumulated beach wrack nearest to the sea influences the sand transport rate for a limited time and is readily removed by storm waves, whereas the uppermost wrack line lasts longer, traps more sand, influences the sediment budget of the existing foredune more directly, and forms the basis of the new foredune crest (Nordstrom et al., 2011).

However, only a part of the beach wrack that reaches the shoreline is included into the food web of the dune ecosystem. For some of the Baltic beaches the residence time of wrack on the shore is often limited to a few days (→ see 3.3 "Residence time"). In exposed areas it is common that most of the wrack deposited on the beaches is flushed back to the sea and does not reach the vegetated beach zone (→ Figure 3.5.1, → 3.5.2).

The aeolian dispersal, accompanied with wave dispersal, of the beach brack was investigated at respective sites in Germany, Estonia and Russia. The research included an estimation of the amount of beach wrack that has been accumulated in "trap – beach wrack catcher" – this means a survey sites in thickets of beach vegetation with an area of 1 m². The observed amount of beach wrack in the vegetation was from 0 to 200 g/m². The largest amount (100–200 g/m²) was found in February and March 2020 in Filinskaya Bay, Russia. This is most likely associated with storms, when wind and waves throw algae inland the beach. The winter of 2019/2020 was mild – there was no stable snow cover, there was no fast ice along the coast. Filinskaya Bay belongs to one of the sites in the Kaliningrad Oblast where beach wrack is washed ashore often due to the closeness of a perennial algae growth in the area of Cape Taran (Volodina & Gerb, 2013) and hydrodynamic conditions. The beach in the bay is gentle and does not have a dune. The vegetation zone is in the back of the beach at a 25–45 m distance from the sea line. The gathering of wrack was carried out completely from the same area of vegetation thickets with an area of 1 m² from September 06, 2019 to August 25, 2020, with a frequency of 1–2 times a month. A total of 380 g/m² (dry algae weight) of algae was harvested during this period, which can be conditionally considered an annual input of beach wrack into the vegetation thickets in this area.

The species composition of algae found in the beach vegetation zone was limited to 5 species at the studied sites, namely eelgrass *Zostera marina, Furcellaria lumbricalis, Fucus vesiculosus, Cladophora* sp., *Vertebrata fucoides*.

At the island of Poel beach (Germany) the main species, both in the new wrack from forebeach and in the wrack from the vegetation zone, was *Zostera marina*. Similarly, *Furcellaria lumbricalis* dominated throughout the year in the wrack in the vegetation zone of the beach in Filinskaya Bay, Russia. Also, in the dense vegetation, a relatively large amount of *Fucus vesiculosus* was found, up to 15 % of the total weight of the wrack. At the same time, the share of *F. vesiculosus* is very small in the new wrack located near the water line, less than 1 %, as well as *Z. marina*. The growth of *F. vesiculosus* and *Z. marina* has not been registered at present within the Russian sector of the southeastern part of the Baltic Sea and, presumably, they are brought in small amounts by currents from the surrounding marine areas (Volodyina & Gerb, 2013).

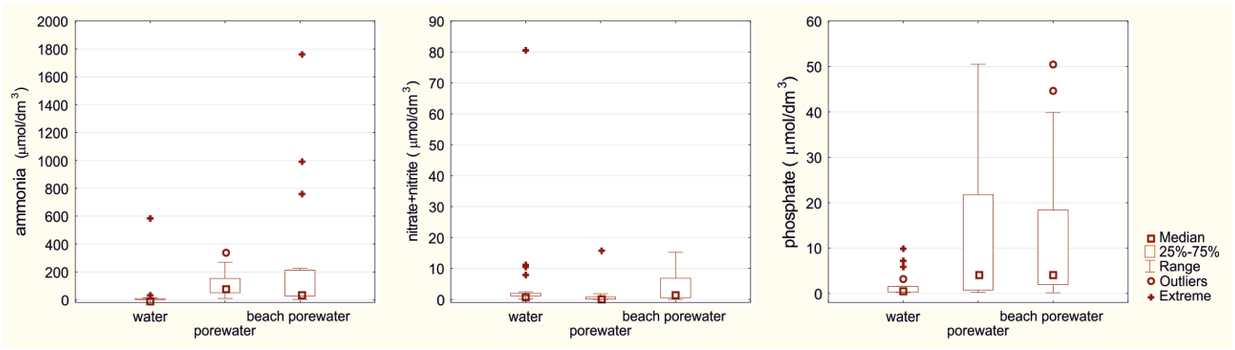


Figure 3.6.1. Phosphate, nitrate+nitrite and ammonia concentrations variability in surface water, sediment pore water and pore water from beach (from under the detritus) from April (2019) to November (2019) (values for 3 sampling sites).

In the light of the studies carried out, different species of algae are subject to varying degrees of aeolian and wave dispersal across the beach. It can be assumed that *F. lumbricalis*, having a branchy structure of the thallus, dries up and becomes "fluffy" and is more easily carried by the wind. *F. vesiculosus* is also branched and has air bladders. When dry, these algae and *Z. marina* usually do not stick together. The relationship between the structure of the thallus of algae and their susceptibility to being washed ashore was also noted by other authors (Orr et al., 2005). At beaches with intermediate and high exposure to wave action, wrack was dominated by algae with air bladders in their structure (e.g. *Fucus* sp.), a factor which, by increasing buoyancy, might assist in them drifting ashore (Barreiro et al., 2011). At the same time, filamentous algae (e.g. *Cladophora* sp., Ulva sp., *Vertebrata* sp.), when dried, strongly stick together, forming dense mats along the coastline or at a short distance from where they were casted by waves. Also these species degrade more rapidly (→ see 3.4.2 "Decomposition rate"). These algae were rarely found in the vegetated zone of the beach.

However, a detailed understanding of the mechanisms and quantification of aeolian (and wave) dispersal of beach wrack in the beaches requires additional scientific research.

3.6 Nutrient availability

Drifting algal mats have recently become a problem in shallow, eutrophic seas worldwide. On the one hand, the excess organic matter washed ashore or deposited on the seabed enhances the growth rates of suspension feeders, while on the other hand it can create local hypoxia events that are followed by changes in zoobenthos abundance, species composition and food web. Marine plant detritus plays an important role in the global carbon cycle and exceeds three-fold the amount of carbon stored in living marine plants. Coastal marine waters are the key areas of plant detritus production and storage. Owing to their permeability, sandy shores have been shown to be very efficient converters of organic matter. To understand the importance of sandy shores in the turnover of organic matter, it is necessary to have a knowledge of detritus production and its biomass (Kotwicki et al., 2005).

One of the important factors which was measured during the sampling campaign under the CONTRA project was the redox (oxidation-reduction) potential. Redox reactions are essential to major element cycling, to many sorption processes, to trace element mobility and toxicity, thus to most remediation schemes, and to the life of flora and fauna itself. Results of the *in situ* measurements in surface and sediment pore waters showed significant oxygen depletion in the warm period and lower annual oxygen levels in the area impacted by algae. Moreover, the results of the measurements indicated that oxygen consumption during algae decomposition influenced an area wider than just that covered with algae wrack, resulting in oxygen depletion in pore waters.

Nutrients were analyzed from surface and sediment pore waters collected in the surf zone and from sediments, sampled from the beach beneath the beach wrack and in two areas in Poland at respective managed (Puck Municipal Beach) and unmanaged beaches (Rzucewo). The amount of beach wrack on the city beach inside the Puck Bay was much lower compared to the unmanaged beach.

Nutrients concentrations were highly variable in all type of studied waters with no clear spatial and temporal trends. In pore water taken from under the detritus at the beach, nutrient concentration was in most cases greater than in the water column and comparable or greater (nitrate+nitrite) to the

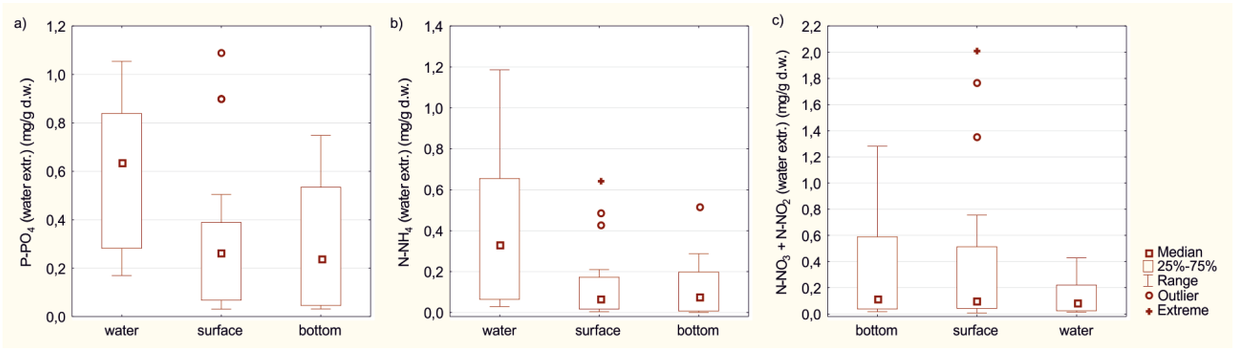


Figure 3.6.2. Variability of water extractable forms of phosphorus and nitrogen in beach wrack sampled from surface water and two layers of sediment beaches.

values observed in porewater (→ Figure 3.6.1).
Variability (RSD) of total carbon (Ctot), nitrogen (Ntot) and phosphorus (Ptot) concentrations in beach-wrack collected from surface water and two layers of beach sediment (surface and subsurface) in the investigated areas between April and November 2019 varied from 29 % to 52 % (→ Table 3.6.1). This indicates a potential varying degree of mineralization, and/or different beach wrack composition. Molar C:N:P ratios in beach wrack suggest that in managed beach the wrack is mineralized to a lesser extent than in unmanaged beach.

Labile phosphorus and nitrogen (water extracted) showed signifficant differences between wrack collected from water and the beach (ANOVA K-W test). In case of $P\text{-}PO_4^{3-}$ (p=0.02) and $N\text{-}NH_4^{+}$ (p=0.02). Those species reached lower concentrations in detritus collected from the beach in comparison to the detritus collected from the water column (→ Figure 3.6.2 a,b). In the case of the sum of $N\text{-}NO_3^{-}$ i $N\text{-}NO_2^{-}$ differences were not signifficant (p=0.76), although in beach wrack collected on the beach concentration were frequently a lot higher than those collected in surface water (→ Figure 3.6.2 c). Observed variability of labile species of N and P reflects nitrification and release of phosphate and ammonia during decomposition of detritus after deposition to the beaches.
Rough estimation show, that in beach wrack accumulated along 100 m of the coast (mean dry wet of beach wrack) at unmanaged stations in Ruzcewo in Poland, the weight of total phosphorus ranged from 18 to 36 kg (→ Figure 3.6.3). Taking to account, the total phosphorus concentration (median) in algae samples classified as living, it can

Table 3.6.1. Statistical outcome of carbon (Ctot), nitrogen (Ntot) and phosphorus (Ptot) in wrack sampled from water column and two layers of sediment beaches in studied managed and unmanaged beaches in Poland, data since April do November 2019).

	wrack origin	N	Mean±S.D. (mg/g d.w)	Min.	Max.	RDS (%)
Ctot	water	15	261±98	76.6	385	38
	beach surface	17	298±124	45.3	445	41
	beach bottom	11	237±123	78.2	429	52
Ntot	water	15	18.5±6.49	5.55	28.8	35
	beach surface	17	19.9±6.85	4.52	31.0	35
	beach bottom	11	18.5±7.18	6.57	32.1	39
Ptot	water	15	1.93±0.55	0.82	3.11	29
	beach surface	17	1.60±0.62	0.66	2.99	39
	beach bottom	11	1.26±0.42	0.44	2.12	33

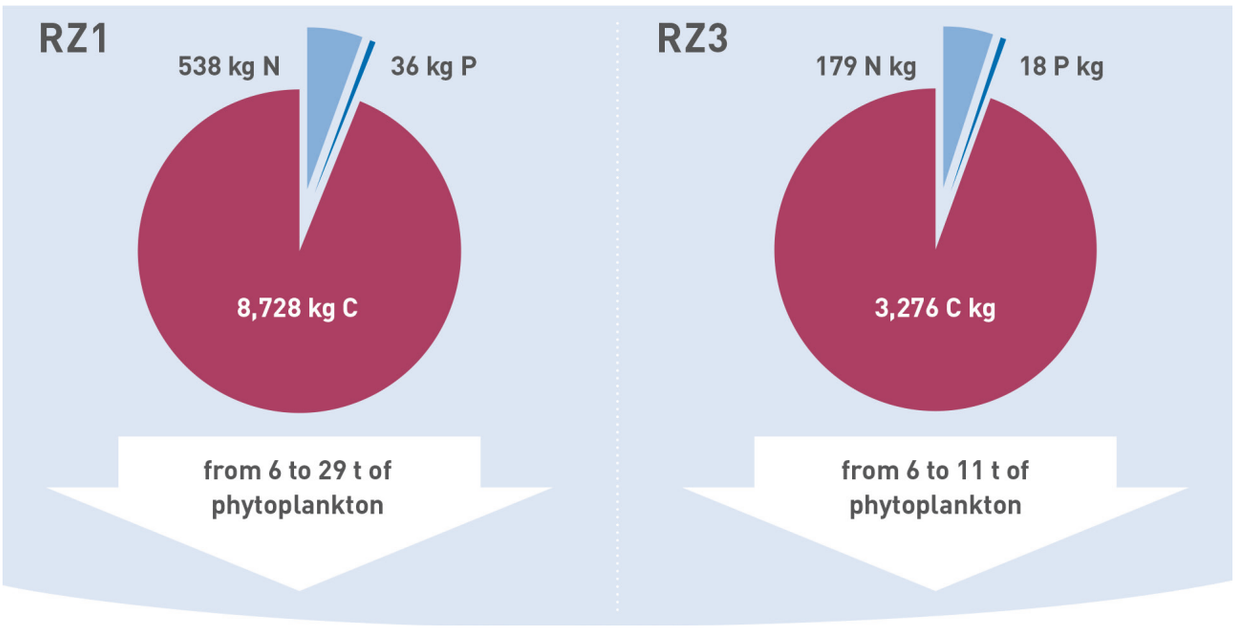


Figure 3.6.3. Mean load (kg) of phosphorus, nitrogen and carbon accumulated in beach wrack (dry weight, kg) at 100 m of unmanaged coast (Ruzcewo beach, Poland, stations Rz1 and Rz3) and potential production of phytoplankton biomass (assumes total decomposition of beach wrack and P limitation).

be roughly calculated, that such a load delivered to the sea water is responsible for the production of 6 to 29 tonnes of phytoplankton biomass (→ Figure 3.6.3).

3.7 Hazardous substances

Along most of the coast, the beach wrack on the beaches does not unduly affect the people who live closeby. However, in certain areas, a proportion of the wrack moving onshore is permanently trapped and may create problems not only for inhabitants of those areas and local authorities, who are responsible to maintain the beaches, but also for the local beach ecosystem. Beached seagrasses and algae release a number of constituents during decomposition and thus alter the coastal biogeochemical cycles and organisms. This includes nutrients and dissolved organic carbon, which will affect flora and microbial activity, and heavy metals (in polluted systems) – which creates risk for biota. Also, emission of volatile components from decaying plant material might constitute a risk for human health (H_2S, Hg0, ^{137}CS), as well as for the climate (methane CH_4). In the presented study beach wrack sediments and water were investigated on the presence of heavy metals, methylmercury, nutrients, bisphenol A (BPA), nonylphenols (NP), octylphenols (OP), polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCB) (for further details see CONTRA-report Möller et al., 2021).

3.7.1 Heavy metals

Heavy metals are natural elements of Earth's crust, but their discharge to the environment due to anthropogenic activity overwhelms their natural concentrations. The most toxic heavy metals that pollute Baltic Sea include mercury (Hg), cadmium (Cd), arsenic (As), and lead (Pb) (Szefer, 2002). Heavy metals can be toxic even at very low concentrations since they tend to accumulate in marine organisms and biomagnify along the trophic chain. In consequence, they can pose a threat to final consumers – humans (Zaborska et al., 2019).

Our investigations under the CONTRA project within beaches of Poland revealed that the concentration of heavy metals in sediments does not exceed the thresholds values given according to Polish laws (Journal of Laws 2002) and HELCOM core indicator. However, in case of zinc (Zn) one magnitude higher concentration was observed in the beach wrack in the unmanaged beach in comparison to sediments (→ Figure 3.7.1). Also chromium (Cr) concentrations need further investigations. The observed difference between Cr levels in sand from the managed (Puck) and unmanaged beach (Rzucewo1, Rzucewo3), as well as sediments from both areas are significant (→ Figure 3.7.2). Measured values indicate that an intake of Cr from the sediments by algae may occur in the heavily overgrown Rzucewo site, and afterwards the element can be transferred to the beach sand due to algae decomposition.

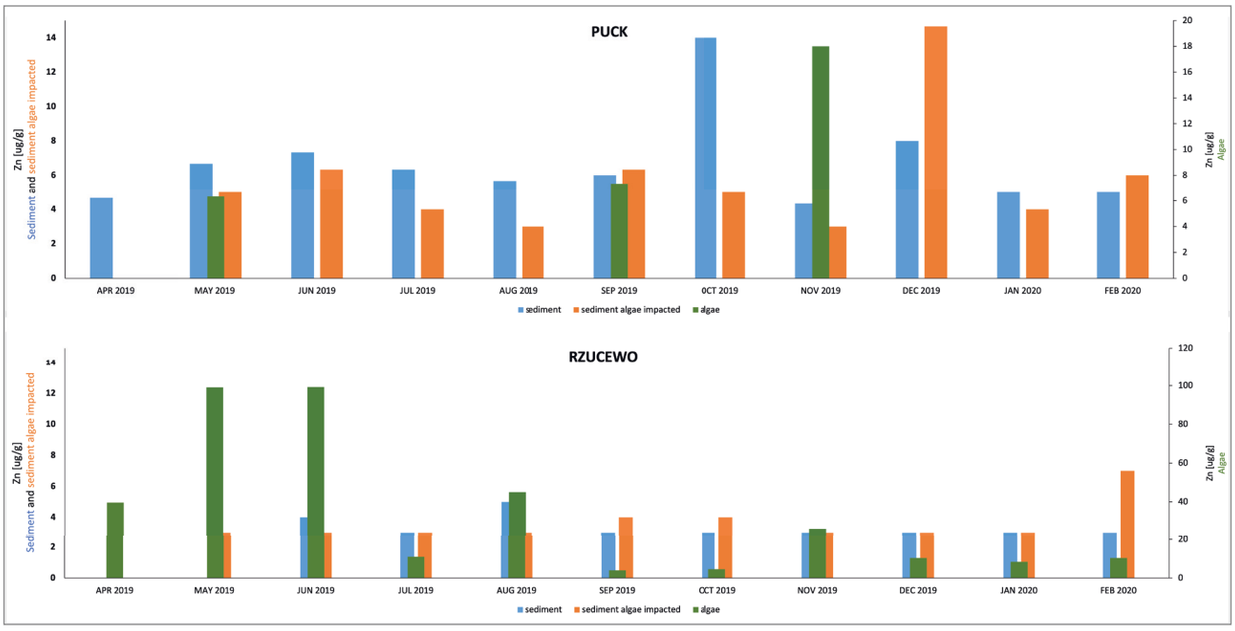


Figure 3.7.1. Zinc concentrations from in situ measurements in sediments with and without the impact of algae in managed (PUCK) and unmanaged beach (RZUCEWO).

Although the data for chromium are only available for one sampling campaign (Poland, July 2019), the preliminary results suggest that beach wrack can be a source of metals for the coastal environment.

Mercury

Anthropogenic mercury (Hg) remains a problem in the aquatic environment, and, based on the sedimentary records in the Baltic Sea, it exceeds Hg coming from natural sources (i.e. hydrothermal processes and rock weathering) on average on a factor of 5). Recently emission of Hg to the environment has substantially decreased (HELCOM and SYKE 2008) resulting also in noticeable decrease of Hg concentration in macrophyta in Polish coastal zone of the southern Baltic Sea. However, in parallel, intense growth of some macrophytobenthos in many areas of the sea bottom has been observed, which is stimulated by an improvement of environmental conditions and lengthening of the growth season. This leads to rapid inclusion of Hg from the water column (which is introduced from both natural and anthropogenic terrestrial sources) and from sediments (which was deposited in the past, and can be considered retarded anthropogenic emission).

In many areas of the Baltic Sea, due to the pattern of currents and shape of the coastline, large quantities of macrophytobenthos gather in the coastal zone, or end up as beach cast. During the summer season in the Gulf of Gdańsk, on 1 km of beach the amount of beached seagrass and algae wrack ranges from several dozens up to 800 tons (Filipkowska et al., 2008, Weinberger et al., 2020). Considering median Hg concentration: 7.6 ng g^{-1} dw (dry weight), it has been calculated that 1 km long beach segment may receive 6 g of Hg per season. About 39 % of the Polish coast is estimated as accumulative zone (Dubrawski et al., 2008) indicating that about 200 km of coastline favors phytobenthos accumulation. During summer season, beach wrack on Polish beaches alone may contain 0.05 to 1.2 kg of Hg (Bełdowska et al., 2015). Recent study performed within the CONTRA project in the Bay of Puck (sheltered part of Gdańsk Bay), indicate that the concentration of Hg in managed beach (Puck), where live algae occurs were clearly lower, than those collected in the unmanaged site, where decomposing wrack was collected (Rzucewo) (→ Figure 3.7.3). However, concentration of Hg in live algae was similar in the unmanaged and managed site. This indicates, that although biological material from the bay accumulates Hg at the same rate and is characterized with the same Hg concentration in both sites, accumulation does not stop on landing. Decomposing beach wrack in unmanaged site is rich in organic matter and continuously builds up Hg concentration. This is probably caused by excellent sorption capabilities of decaying plant and algae material. It may capture mercury from coastal water, acting as a filter for surf water. Another explanation is Hg capture from

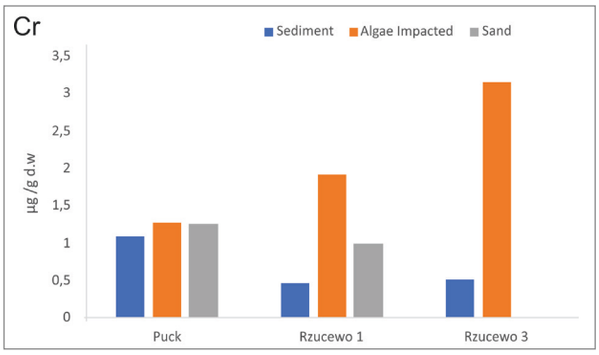


Figure 3.7.2. Chromium concentrations in sediments with and without beach wrack (impact of algae) in managed (PUCK) and unmanaged beach (RZUCEWO) in July 2019.

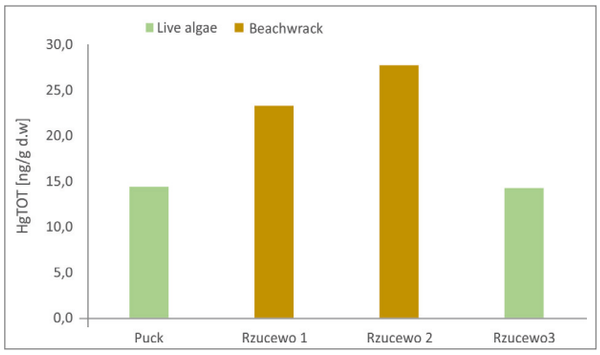


Figure 3.7.3. Total mercury concentration in live algae at managed site (P1), decaying beachcast at unmanaged site (Rz1, Rz2) and live algae at unmanaged site (Rz3).

atmosphere, where it originates in low emission from local sources. This means, that unmanaged beaches may not only transfer Hg from beachcast via accumulation in live algae and subsequent release, but additionally enhance Hg flux to the beach from local sources.

Methyl mercury

Methylmercury (MeHg) is the most toxic and dangerous form of mercury occurring in the environment. MeHg is highly bioaccumulative in organisms and undergoes biomagnification via the food chain. The environmental conditions promoting methylation processes and production of MeHg are anoxic conditions, presence of high contents of organic matter, and the presence of the specific microorganisms. All of those conditions are present in the beach wrack. However, results from the measurements of MeHg in sediments and sand do not give a definite answer if the beach wrack promotes the production of MeHg. For unmanaged beach (Rzucewo, Poland) in June 2019, the highest concentration of MeHg, 20 pg g^{-1} dw (dry weight) was measured in algae impacted beach sand in comparison to the not impacted site (8 pg g^{-1} dw) and sediments collected from water (5 pg g^{-1} dw). However, in July 2019 the highest concentration was in sediments collected from water (45 pg g^{-1} dw) in comparison to algae impacted beach sand (6 pg g^{-1} dw) and not impacted sand (<LOD). In case of the managed beach in Puck, both in June and July 2019, MeHg was detected only in sediments at low concentration (8–10 pg g^{-1} dw), and in the sand from beach concentration was below the detection limit (<LOD).

3.7.2 Organic contaminants

Organic pollutants persist in the environment, are toxic, bioaccumulate in biota, undergo biomagnification along the trophic chain and can be transported over long distances. In this study, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) as well as endocrine disrupting compounds (EDCs) like bisphenol A (2,2-bis-(4-hydroxyphenyl) propane – BPA), and alkylphenols: 4-nonylphenol (4-NP) and 4-*tert*-octylphenol (4-t-OP) were selected as representative persistent organic contaminants (POPS).

Seven PCBs and sixteen PAHs were analysed in sediments (1 m depth), beach sand and algae samples collected in July 2019 from beaches in Poland. In case of Σ7 PCBs concentration levels ranging from <LOQ (1.1 ng g^{-1}, dw (dry weight)) to 81.8 ng g^{-1} dw in algae and beach wrack and from 2.3 to 17.0 ng g^{-1} dw (dry weight) in sediments and beach sand (→ Figure 3.7.4). Investigation of Σ16 PAH showed concentration levels from 1237 to 21708 ng g^{-1} dw in algae and beach wrack and from 128 to 2590 ng g^{-1} dw in sediments and beach sand (→ Figure 3.7.4). For both groups of contaminants highest concentration was detected in algae and beach wrack samples from unmanaged station. In the case of sediments and sands samples, the highest concentration was detected in no impacted sand in comparison to impacted for PCBs and no differences were observed for PAHs.

Results of PCBs and PAHs show that beach wrack is able to accumulate those contaminants. On the other hand, comparision of impacted and not impacted regions suggest that beach wrack probably adsorbs PAHs and PCBs from the beach and their concentration is lower in impacted regions. The fate of PCBs and PAHs in the investigated region is more complicated than suspected and should be investigated in future.

Bisphenol A (BPA), and 4-nonylphenol (4-NP) were

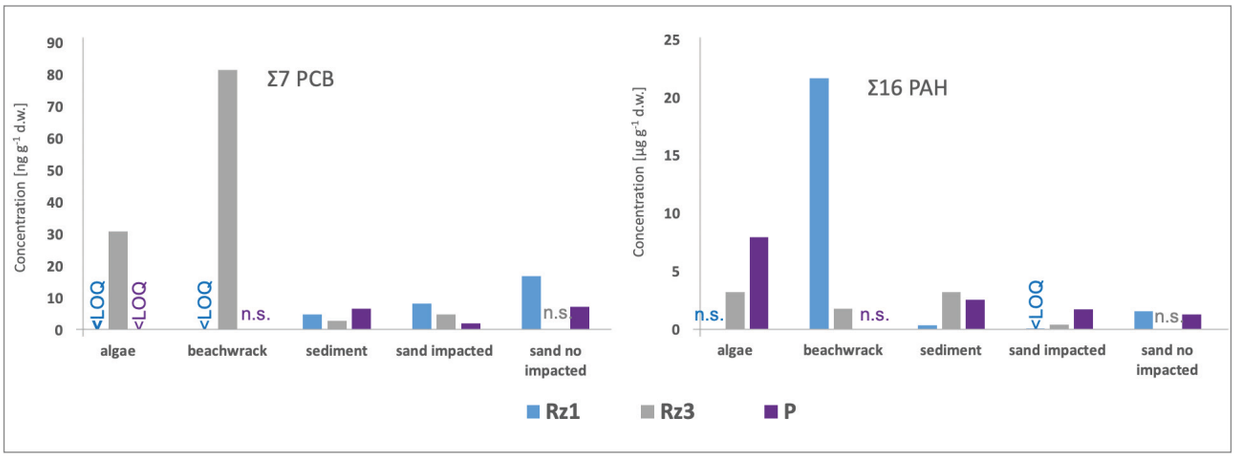


Figure 3.7.4. Concentrations of Σ7 PCBs and Σ16 PAHs in July 2019 in unmanaged beach of Rzucewo (Rz1, Rz3) and managed Puck beach (P). n.s.- no sample, <LOQ – below limit of quantification. Sediment indicates the sand samples collected from 1m water depth and sand (impacted/no impacted) indicates the sand collected from beach area.

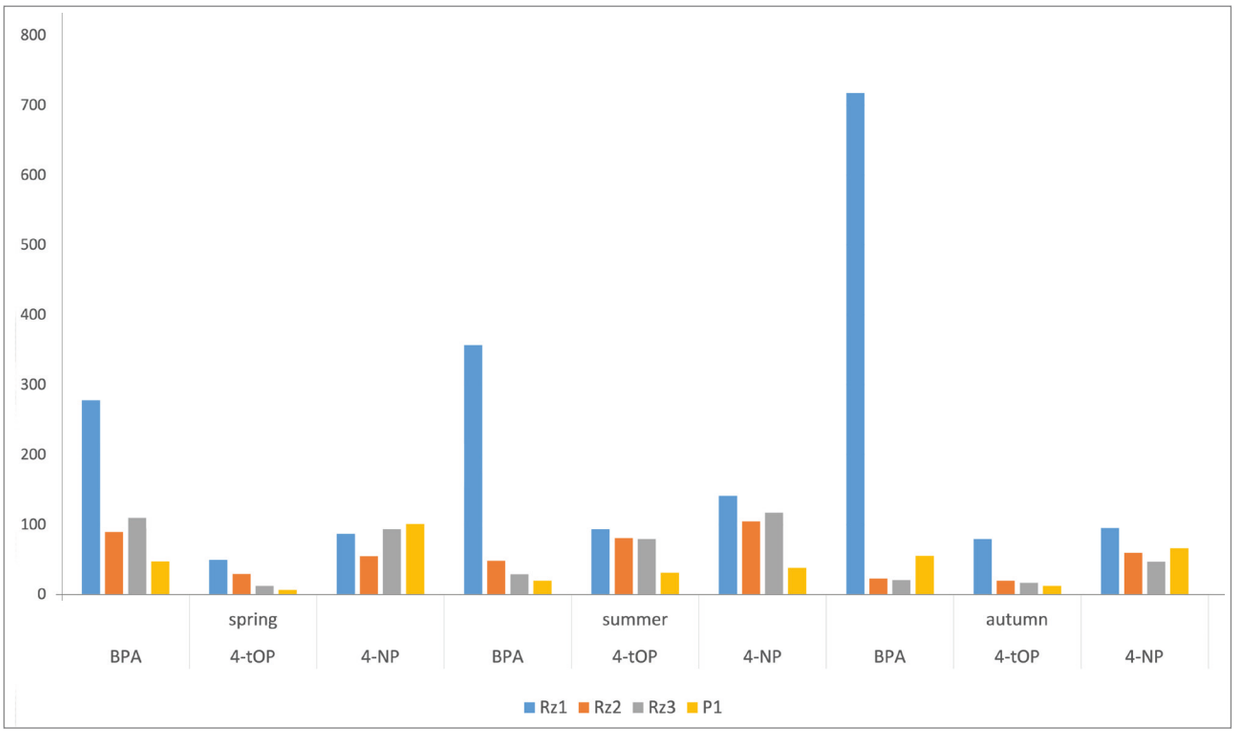


Figure 3.7.5. Concentrations of bisphenol A (BPA), 4-tert-octylphenol (4-t-OP) and 4-nonylphenol (4-NP) ng.g-1 dw depending on from season and station.

identified in all samples and the 4-tert-octylphenol was present in 80 % of samples. The highest concentrations were observed for BPA and then for 4-NP. The maximum average concentrations were recorded for unmanaged beach (Rzucewo, station Rz1: BPA 450.7, 4-t-OP 74.1 and 4-NP 107.8 ng g dw) and the lowest for managed beach (Puck, reference station P1: 40.6; 16.6; 68.5 ng g dw respectively). Variability of concentration depended on station and season (→ Figure 3.7.5). Our research indicate that the microalgae may have potential to accumulate bisphenol A, 4-tert-octylphenol and 4-nonylphenol and may result in the pollution of beaches exposed to dead plants or the transfer of dangerous compounds up the food chain.

Based on the obtained results, we can confirm that the beach wrack can release the contaminants accumulated by algae during their lifetime from seawater and sediments. Moreover, mercury studies indicate that beach wrack deposited on beaches continues to accumulate dissolved substances from seawater. Contaminants are being released

to the coastal zone during decomposition of organic matter, partly to groundwaters, which are returning to the sea, and partly to atmosphere via volatiles. Moreover, presence of large quantities of organic matter, and the fact, that contaminants were already absorbed by marine plants and algae, results in enhanced bioavailability of contaminants, as compared to seawater where they came from. The process itself is cyclic – contaminants are being removed from seawater and sediments by marine plants and algae, in areas located at considerable distance from the coastal zone. In case of the Puck Bay, this included the entire bay and Gulf of Gdańsk. Then the algae is washed ashore in several locations, building up the metal and organic contaminants pool in these spots. During decomposition, bioavailable forms of contaminants are released to the coastal zone, where biota can absorb it and transfer them to the foodchain. Breaking this link, by removal of beach wrack after deposition, can result in the depuration of the ecosystem.

3.8 Human-produced litter

Marine litter is defined as any persistent, manufactured, or processed solid material discarded, disposed of or abandoned in the marine and coastal environment. Litter consists of items that have been made or used by people and deliberately discarded or unintentionally lost into the sea or on beaches, including such materials transported into the marine environment from land by rivers, draining or sewage systems, or winds. Marine litter can be found in all marine compartments (beaches, sea surface and water column, seafloor, ingested by biota) both in remote areas and close to populated areas (Galgani et al., 2013).

Presence of litter in the marine environment and beaches is a globally raising concern. Within beaches the litter directly affects the beach ecosystem and also brings more responsibilities to municipalities and authorities in order to keep the beaches and thus marine environment clean. Beach litter, especially the one of plastic, is stated as environmentally, economically, and psychologically negative and the most positive aspect regarding beach litter is the lack of it (e.g. Galgani et al., 2019; Wyles et al., 2016). One item of 'beach litter' is defined as any discarded item found on the beach over 2.5 cm in length (namely macro litter, including cigarette remains). Beach litter can be both – either marine origin, that is carried to the beach via currents/water or land-based origin e.g. left to the beach by visitors or carried through e.g. winds. Also from the beaches the litter can e.g. move either into the water environment, move inland, and also be ingested by birds and animals. Nevertheless, it is easier for people to remove the litter from the beaches than from other marine compartments.

The amount of beach litter varies greatly across the globe, but present studies confirm that all coastal regions, both in remote areas and close to populated areas, are affected by litter somehow. E.g. in the Mediterranean Sea region the values of litter can be over 6000 items (in size >2.5 cm) per 100 m long beach section (Vlacogianni et al., 2019). However, across Europe, the presence of litter on average is generally lower: in 2015 and 2016, the average beach litter quantity was estimated to 150 litter items per 100 m long beach section, with different averages in different regions: 40 items per 100 m around the Baltic Sea; 106 items per 100 m around the Black Sea; 233 items per 100 m around the North-East Atlantic and the North Sea and 274 items per 100 m around the Mediterranean Sea (van Loon et al., 2020). The Baltic Sea region is currently regarded as the cleanest area in Europe in the means of beach litter, nevertheless, the average amounts of litter items per 100 m of beach section are estimated to 50–300 (HELCOM, 2018ab). When looking closer, then within the Baltic Sea region the average number of beach litter items has been estimated to about 280 litter items per 100 m on urban beaches and up to 47 items per 100 m of shoreline on natural beaches (HELCOM, 2018).

Presence of litter within the beach wrack that is removed is one aspect that needs to be studied locally when searching or choosing for further beach wrack processing options. In the beaches the litter can be removed separately or together with beach wrack. There is also great variety in litter items when it comes to e.g. material, hazardousness, size, origin, and the presence of litter just makes the beach wrack a more complicated raw material for further processing (GESAMP, 2016; Veiga et al., 2016). When big and visible litter items can be removed easily by hand-picking, then the smaller items that are entangled or buried into the beached algal material are harder, if not impossible, to sight and remove. Microlitter (litter items in size < 5 mm) and nanolitter (generally litter items in size < 0.001 mm) surveys within the beach wrack need a more specific approach.

In the CONTRA project litter was mapped in 18 beaches that were visited monthly in a one-year period (CONTRA-report Möller et al., 2021). In total 2289 litter items were removed from the study

Table 3.8.1. The share of litter materials in studied managed and unmanaged beaches.

	Managed beach		Unmanaged beach	
Material	No of items	%	No of items	%
Artificial polymer materials	957	72.17	695	72.17
Chemicals	3	0.23	1	0.10
Glass/ceramics	116	8.75	94	9.76
Metal	99	7.47	31	3.22
Food waste	2	0.15	8	0.83
Undefined	4	0.30	7	0.73
Paper/carbord	61	4.60	40	4.15
Rubber	21	1.58	23	2.39
Cloth/textile	25	1.89	34	3.53
Processed/worked wood	38	2.87	30	3.12

areas in period April 2019–March 2020. 1326 litter items originated from managed beach sections and 963 from unmanaged beach sections.

Throughout the study period, most of the litter items were collected from the chosen beaches in Estonia and Poland where the record „catches" were 127 and 116 respectively, with both records originating from managed beach sections. In other studied beaches in Denmark, Sweden, Germany and Kaliningrad the number of found litter items remained mostly under 20 items per 100 m of beach section. The threshold value of 20 litter items per 100 m long beach section is also agreed on to represent the good environmental status regarding beach litter (van Loon et al., 2020).

Most of the litter found on the European beaches is plastic-based (Addamo et al., 2017), our studies within the CONTRA project confirmed the previous findings – both in managed and unmanaged beaches the share of plastic among other litter materials was 72 % (→ Table 3.8.1). For other materials, there was little difference between managed and unmanaged beaches.

Most common findings within the CONTRA project were cigarette remains, plastic pieces, food containers and candy wrappers, plastic bags, plastic bottle caps, glass fragments, glass bottles and jars, plastic rope (pieces), plastic foam sponge, metal caps and pull tabs (→ Table 3.8.2). Out of different 82 litter categories under UNEP 56 categories were recorded in the studied beaches. The findings were in accordance with earlier similar studies (e.g. Addamo et al., 2017) showing that most of the litter found on the public beaches is related to simple leisure activities and originate from land-based sources. Numerous cigarette remains in unmanaged beaches are mostly explained by findings in Kakumäe unmanaged beach – the beach is located within the city and is a popular place all year round. Other studied unmanaged beaches are located further away from populated areas and the share of cigarette remains in those beaches was considerably lower. Based solely on observations the size of litter items was in most cases below 10 cm. Presence of large and heavy objects of size > 1 m (e.g. tyre, mattress, wooden pallet) was observed in few times. The amount of litter varied greatly among months, especially in the managed beaches of Estonia and Poland. However, no specific pattern can be brought out here at present (CONTRA-report Möller et al., 2021).

Our findings indicated that most of the litter items found on the beaches were related to beach wrack – in total 45 % of litter were found together with old wrack (within old wrack line), 26 % was found together with new wrack (new wrack line) and 29 % of litter was found from the rest of the beach area. There were variations between beaches but the general pattern indicates that litter and beach wrack do move together and similarly, especially in the unmanaged beaches.

Another topic is microlitter pollution at the beaches. Within the CONTRA project we did not specially investigate meso- and microlitter, but it was

Table 3.8.2. Most common litter items in studied managed and unmanaged beaches.

Managed beach		**Unmanaged beach**	
Litter item	%	Litter item	%
Cigarette remains	31.38	Plastic (other)	18.92
Plastic (other)	16.18	Cigarette remains	15.89
Food containers, candy wrappers	5.78	Food containers, candy wrappers	8.11
Glass bottles and jars	5.45	Plastic bottle caps and lids	7.78
Metal bottle caps, lids and pull-tabs	4.46	Plastic bags	7.68
Plastic bags	4.46	Glass or ceramic fragments	5.95
Glass or ceramic fragments	3.96	Foam sponge	4.97
Plastic rope	2.89	Plastic rope	3.35
Plastic bottle caps and lids	2.81	Glass bottles and jars	3.24
Paper (other)	2.73	Wood (other)	2.81

determined from the biomass samples collected from Kakumäe beach, Estonia and Filinskaya Bay, Kaliningrad Oblast, Russia. Mesolitter is litter items in size of 5–25 mm length or diameter and microlitter is in size < 5 mm. In Kakumäe beach, out of 129 analysed biomass samples 55 (in total 43 %) contained some piece of still visible microlitter piece/item in a size range of 1–5 mm. In the Filinskaya Bay out of 109 processed samples, 28 % contained mesolitter. 77 % of the findings were pieces of polyethylene. Based on findings from Filinskaya Bay, it was estimated that on average 1 m^3 of beach wrack contained about 0.06 m^3 of polyethylene.

When the beach wrack is removed for beach cleaning purposes, it is also removed together with sand (see → chapter 4 "Mechanical disturbance"). Recent studies on the microlitter pollution in the Baltic Sea beach sediment indicated another problem. Based on a survey carried out in the 12 beaches in southern Baltic Sea (Polish coast) the amount of microplastic varied between 76 and 295 items per kg dry sediment. Fibres and plastic fragments were the dominant microplastic types (Urban-Malinga et al., 2020). The amount of nanoplastic in the Baltic Sea sandy beaches is currently not known. Consequently, based on the share of plastic pollution and microplastic at the beaches it cannot be advised to use beach wrack directly for soil improvement on the agricultural fields as microplastic pollution on agricultural fields is a growing concern (Nizzetto et al., 2016; Henseler et al., 2019; Gavigan et al., 2020). The consequences of microplastic pollution in the agricultural fields for sustainability and security of food production are currently unknown.

With globally raising marine pollution, littering of dunes is another aspect that has not gained much attention previously (Šilc et al., 2018, Concalves et al., 2019), but amount of litter has been shown to increase along the sea-inland gradient with foredunes and pineforests having the highest litter coverage with main litter material plastic, polystyrene and glass (Šilc et al., 2018). At the same time dunes are often very fragile to mechanical disturbance (both by foot and machines). Thus in beach management and cleaning it is important to have a wider view on the whole beach ecosystem and prevent the beach littering in the first place and also prevent the moving of beach litter towards inland and marine environment.

The amount of litter on the beach ecosystems and both within the beach wrack and sediments should be monitored on a local basis and taken into account when searching for further use possibilities of removed beach wrack – in other words: among other aspects the amount and nature of litter significantly affects the treatment options and possible further use of beach wrack.

4 Disturbance on sandy beach ecology due to beach management activities

The ever-increasing human activities on the beach and developments in the surrounding area have led to the endangerment and often destruction of the typical flora and fauna in recent decades and even centuries (Davenport & Davenport, 2006). In addition to littering, humans are taking up more and more space and thus becoming the strongest competitor for the natural flora and fauna of the beach ecosystem. Thus, it is difficult to find a sandy beach especially on the southern part of the Baltic Sea coast that is not and has not been influenced by humans.

Furthermore, due to the high interest for clean beaches, the beaches are increasingly being cleaned to remove nuisance biomass and waste. The frequency and type of cleaning activities are adapted to local and weather conditions as well as the expected amounts of beach wrack (→ chapter 3.1). As beach cleaning is carried out in highly human colonized and thus frequented areas, the human impact is probably particularly high here. There are mainly two types of beach cleaning procedures: mechanical and manual. Mechanical beach cleaning is defined as litter and/or organic material removal based on the work of automatic machines that rake or sieve the most superficial layer of sand. Manual cleaning involves people picking up litter by hand only or/and using hand-held rakes to collect beach wrack – this interferes less with nature, but is also carried out less because of the personal costs.

Earlier studies have presented that managed beaches are wider than the natural ones, have much less vegetation, lower biodiversity, fewer „natural" dunes and much flatter topographic features than unmanaged beaches (overviewed e.g. in Schumacher, 2008; Dugan & Hubbard, 2010). Many of the beaches are also flushed with sand manually during the autumn-spring months, or the sand is moved from one place to another with machines, in order to provide tourists with a wide beach during the summer season. Thus very popular beaches are heavily modified in their ecosystem characteristics for many decades.

As beach wrack accumulates on the beach, it contributes to the reduction of wave energy and currents in the shallow water/swash zone, serves as trap and stabilizes the sediments in front of the beach (→ section 3.1). This could reduce sand loss and erosion already at the swash zone. Despite this potential importance for coastal protection, international studies on beach wrack composition and quantities under seasonal and spatial aspects are surprisingly scarce for the Baltic Sea coast (CONTRA-report Möller et al., 2021). Accordingly, the coastal protective effect for impact on hydrodynamic features of the shore line has not yet been studied as well.

On the other hand, in the case of larger quantities of beach landings, removal could decrease potential higher nutrients and pollutants release at the beach, which could possibly return to the water and thus maintain eutrophication and/or pollution of the Baltic Sea (→ chapter 3.7). Furthermore, the parallel removal of litter is better for wildlife (→ chapter 3.8). However, what it ultimately means for the ecosystem to specifically remove biomass for the purpose of Baltic Sea remediation is not known so far.

Consequently, a lot of far-reaching impacts of human activity on the beach ecosystem are assumed, but there is a lack of sufficient ecological studies for the Baltic Sea coast, which explicitly deal with this complex topic. Consequently, a comparative study in six different countries and corresponding study sites was initiated under the CONTRA project.

4.1 Mechanical disturbance

Due to frequent and regular traffic (e.g. cleaning, backfill), beaches are transformed more and more into larger areas of sand, while smaller sand hills and newly formed dunes are flattened (Schumacher, 2008). For mechanical cleaning



Figure 4.1.1. Beach wrack removal in Germany (Island of Poel) using heavy machinery (Photos: J.Hofmann).

heavy vehicles such as e.g. tractors pulled sieving machines are used commonly (→ Figure 4.1.1). It can easily be imagined that this may lead to compaction of the sediments/soils, for instance by the sheer weight of the machinery exerting enormous pressure on upper beach layers (Gheskiere et al., 2005). On the one hand, the sediment is compacted, especially in the sensitive swash area, where the beach wrack is preferably removed. On the other hand, the sediments are constantly redeposited by the insertion of rakes to a depth of up to 30 cm. While there are no studies that focus specifically on the mechanical impact of beach cleaning vehicles, evidence for the disturbance of beach ecosystems through recreational driving with off-road vehicles on beaches is well established (Houser et al., 2013). Sand-dwelling microorganisms and invertebrates were hampered e.g. in the construction of new living tubes and/or existing ones were destroyed. They are therefore no longer able to live in the swash area as a habitat or, if possible, have to retreat to not disturbed sections of the beach. This in turn affects the abundance and biodiversity of the species that feed on the inhabitants of the beach wrack infauna by depriving them of their food source (Defeo et al., 2009, → chapter 3.2).
In addition, the presence of the machines and corresponding noise/scare effect can disturb the presence and/or behavior of wildlife like birds even if it is only for a short time.
Dugan et al., (2003) found that the "cleaned" areas of a beach had significantly lower rates of plant survival and reproduction after germination than the "not cleaned" areas of the same beach. As vegetation abundance decreases and the height and presence of dunes decreases, sand transport patterns change in ways that promote the extent of flattened topography. Dunes, beach wrack and vegetation act as barriers that slow down the wind-triggered movement of sand. The disappearance of these features may prevent the formation of future dunes. As beaches become flatter and wider, the abundance and diversity of vegetation decreases further, as vegetation requires stable sand dunes to take root and grow. In this way, mechanical beach cleaning triggers a positive feedback loop that reinforces the flattening and widening of beaches and the loss of vegetation abundance and diversity. Using beach wrack as compost layer to build up dunes or sand catching fences, as shown in case study 4 within the CONTRA (CONTRA-report Chubarenko et al., 2021), for example, could counteract this effect.
One important aspect regarding mechanical disturbance due to beach wrack removal is also the removal of sand from the beach ecosystems. In our study all biomass samples of beach wrack were collected by hand and no special treatment (e.g. shaking off the sand) was applied. Analysis of biomass samples collected from Kakumäe beach (Estonia) showed that the sand proportion in total dry weight of removed beach wrack can be as high as 97 % with an average of 58 %. On average, the share of sand in new wrack was 62 % (±26) and in the old wrack it was 54 % (±33). In our study it equaled to on average of 2.5 kg of sand (dry weight) per 1 m² that was removed together with beach wrack from new wrack line and to 4.1 kg of sand on average per old wrack line. The maximum values reached up to 22 kg of sand removal per m², these high values were observed in thickest lines of old and new wrack (17 and 12 cm, respectively). The smallest amounts of sand were removed together with old wrack at winter period, where the old and relatively dry wrack consisted mostly of the remnants of reed *Phragmites australis*.

4.2 Sand compaction

Sand compaction and its potentially negative



Figure 4.3.1. Four study sites for wildlife observations off the German Western Baltic Sea coast.

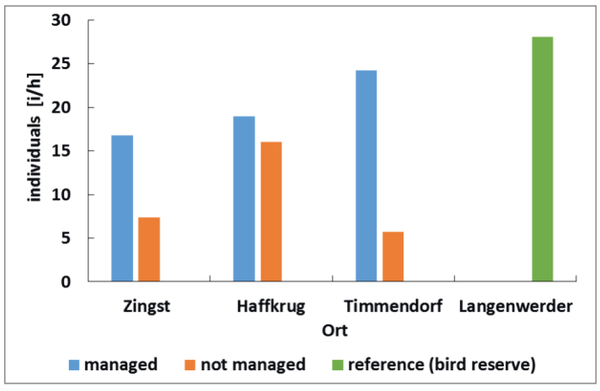


Figure 4.3.2. Bird individuals per hour [i/h] and beach area within 1–4 days (n=1–4) in July and August 2020. (Germany).

impact on beach ecosystems was discussed in a comprehensive review of Speybroeck et al., (2006): they highlighted this as a well-known side-effect of beach stabilization measures such as beach nourishment. While findings from this review may certainly be applicable in a broader scope, research specifically focusing on compaction issues related to mechanical beach wrack removal are scarce.

Therefore, the compaction of sand was investigated during the CONTRA project by several bulk density measurements at respective sites in Denmark, Germany, Russia and Estonia (for more details see CONTRA-report Möller et al., 2021).

Our investigations showed the strongest compaction in the swash area decreasing in comparison to the lanes of the machines and the "undisturbed areas" in front of the dunes. However, in the swash zone the sand was also permanently compacted by moisture and wave motion. In addition, it is likely that not only sheer weight of the machinery contributed to the sediment compaction, but also the walking of people. This so-called footfall load has also been investigated and indicated significant compaction of the sand and lower biodiversity of the infauna (Schumacher, 2008).

In the back area of the beach, the sand was much more loosely bedded, thus it depended on where exactly the sample was taken and some of the sand was churned up again at the edge of the tyre print lane. Furthermore, on the Island of Poel (Germany), the vehicles also drove along the "unmanaged areas" to support the cleaning procedure. As this is a common practice, these beaches were included in the investigations, but also complicate the evaluation of the data.

Despite these many impacts on the interpretation, our results indicate that there were differences between undisturbed areas and traveled tracks, even if they are only slight. It can give a small indication of the trend to be expected. Further studies would hence be required and should include a more detailed comparison with natural and undisturbed beaches. It is very likely that temporary structures for instance from burrowing invertebrates may nevertheless be destroyed by over-drive of heavy machinery and the use of deep sediment penetrating forks in beach cleaning. Moreover, numerous studies on the environmental impact of beach nourishment, have brought the evidence that compaction negatively affects the diversity of beach inhabiting invertebrates (Speybroeck et al., 2006).

4.3 Effect on biodiversity

Besides the before-mentioned disturbances related to the use of heavy machinery in beach cleaning, the removal of beach wrack itself has the potential to affect beach biodiversity as well. According to various studies summarized in a review by Defeo et al. (2008), the beach wrack cover of the beach and the abundance of shorebirds were positively correlated. In addition, the general loss of dune vegetation contributes to an increased nestling mortality of dune nesting bird species (Watson et al., 1996). Nests are likely to be abandoned with a higher frequency due to disturbance caused by the vehicles, on areas lacking protective vegetation, which in turn increases the risk for nestling predation. There is little controversy about the significant contribution of driving on beaches to the decline of dune breeding bird populations observed in coastal areas heavily affected by tourism, for instance in Australia, Great Britain, and South Africa (Watson et al., 1996, Weston et al, 2014). In fact, on beaches with beach cleaning, there is hardly any breeding activity at all. As stated by Defeo et al. (2008) it is clear that a ban on the use of off-road vehicles

Table 4.3.1. Overview of all birds observed in 2020, shown as individual number [i], study day (n=1–4) per beach section. ZIN= Zingst (22.-25.07.), HFK= Haffkrug (17./23.8.), TM= Timmendorf (25.08.-29.08.), LAN= Island of Langenwerder (25./29.8.) (Germany); man. = managed; unman. = unmanaged; ref.= reference; X = occurrence of a species on the respective beach section; – = species not observed. Grey marked bars indicate synanthropic/"culture follower" species (according to Janke & Kremer 1993).

family	species	ZIN man. n=4	i	ZIN unman. n=4	i	HFK man. n=1	i	HFK unman. n=1	i	TM man. n=2	i	TM unman. n=2	i	LAN ref. n=2	i
Anatidae	*Anas platyrhynchos*	-	0	-	0	-	0	-	0	-	0	X	1	X	18
Charadriidae	*Charadrius hiaticula*	-	0	-	0	-	0	-	0	-	0	-	0	X	8
Columbidae	*Columba palumbus*	-	0	-	0	X	2	X	7	-	0	-	0	-	0
Corvidae	*Corvus corone cornix*	X	4	X	21	X	3	-	0	-	0	-	0	-	0
	Corvus corone	-	0	-	0	X	8	X	4	-	0	-	0	-	0
Haematopodidae	*Haematopus ostralegus*	-	0	-	0	-	0	-	0	-	0	-	0	X	3
Hirundinidae	*Delichon urbicum*	-	0	-	0	-	0	-	0	X	4	-	0	-	0
	Sterna sp.	-	0	-	0	-	0	-	0	-	0	-	0	X	2
Larinae	*Larus ridibundus*	X	112	X	44	X	22	X	18	X	6	X	1	X	18
	Larus argentatus	X	24	X	9	X	3	X	3	X	21	X	7	X	6
	Larus canus	X	5	-	0	-	0	-	0	-	0	-	0	-	0
Motacillidae	*Motacilla alba*	X	33	X	2	-	0	-	0	-	0	X	6	-	0
Phalacrocoracidae	*Phalacrocorax carbo*	-	0	-	0	-	0	-	0	-	0	-	0	X	1
Scolopacidae	*Calidris alpina*	-	0	-	0	-	0	-	0	-	0	-	0	X	50
	Gallinago gallinago	-	0	-	0	-	0	-	0	-	0	-	0	X	5
	Numenius arquata	-	0	-	0	-	0	-	0	-	0	-	0	X	5
	Calidris canutus	-	0	-	0	-	0	-	0	-	0	-	0	X	9

on beaches would have had a positive effect on the coastal bird populations of the corresponding beaches. However whether this will be enough to bring the sensitive shorebird species back remains questionable due to the increasing human presence.

Animal communities inhabiting sandy beaches rely heavily on seaborne inputs of carbon and organic materials since *in situ* productivity is very low (Brown & McLachlan, 1990). Beach wrack, thereby, constitutes the major allochthonous subsidy for these ecosystems. Hence, its frequent removal can affect the productivity and standing crop of primary and secondary consumers in beach inhabiting communities. Indeed, numerous studies found that the removal of beach wrack led to a decrease in diversity, abundance, total biomass of beach inhabiting meio- and macrofauna e.g. macro invertebrates (→ chapter 3.2), indicating the existence of bottom-up effects. Consequently, macrofaunal species at higher trophic levels including shore birds may hence be negatively affected as well (Orr, 2013). Dugan et al. (2003) concluded that the recovery of beach ecosystems from disturbances such as beach wrack removal towards an ecological status similar to undisturbed conditions might take years. A modelling study by Orr (2013) indicated that shore bird populations on western Scottish beaches may need up to 20 years to recover from a decline caused by beach wrack harvesting.

Within the CONTRA four study areas on the Baltic Sea coast of Mecklenburg-Vorpommern and Schleswig-Holstein (Germany) were chosen for the investigation of the impacts on birds: Zingst, Haffkrug and the Island of Poel (Timmendorf) including the nearby Island of Langenwerder, a bird sanctuary, as a reference area for natural conditions (→ Figure 4.3.1).

The beach wrack coverage/amounts were not necessarily correlated with the presence of birds that could feed on beach wrack fauna (for more details CONTRA-report Möller et al., 2021). With a total of 416 individuals counted, the share of cultural followers/synanthropic species amounted to 85 % of all observed birds (i=495), which prefer likely other food sources. The cultural followers dominated with 89 % (i=416) at the managed and unmanaged sites (→ Table 4.3.1). Whereas individuals of other sensitive shorebird species (i=79), susceptible to disturbance and dependent on beach wrack infauna, as well as species assessed as vulnerable in the Red List, have only been observed in the reference area.

This trend towards reflecting more natural conditions for the wildlife in areas without human influence is also confirmed by the presence of individuals per site (→ Figure 4.3.2) or biodiversity values (→ Figure 4.3.3). The highest bird individual presence with 28.1 [i/h] and biodiversity with 1.9 [H'] was determined in total in the reference area. The lower biodiversity values at the managed and unmanaged beach sections were correlated with the dominance of two Larinea species *L. ridbundus* and *L. argentatus*. However, the lowest values were

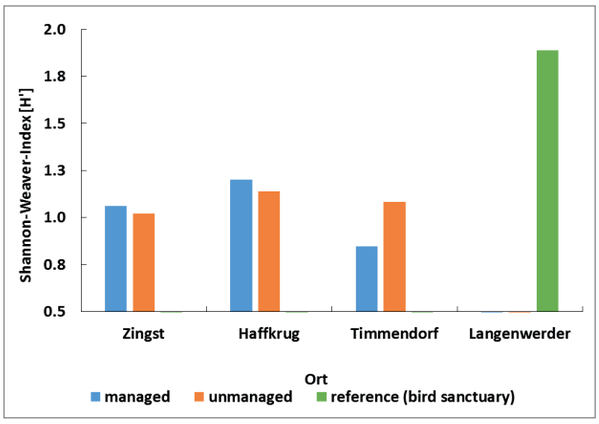


Figure 4.3.3. Biodiversity at the different sites at German beaches according to Shannon-Weaver indices; managed in total (H=1.3), unmanaged in total (H'=1.4) and reference area (H'=1.9).

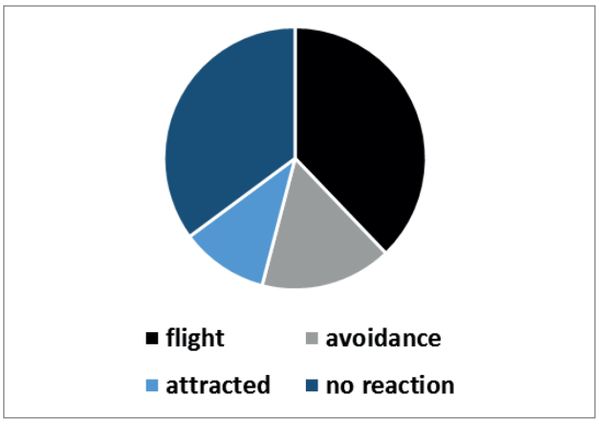


Figure 4.3.4. Reactions per individual (i=37) exposed to cleaning activities (n=4) regardless of vehicle type, site and study time (Germany). Only *Larus ridbundus* (i=24) and *Larus argentatus* (i=13) were considered as these were present at all sites.

counted at the unmanaged sites with 8.2 [i/h] and 1.4 [H'] in total. This could be explained by a certain attraction effect when foraging on managed beaches. Sometimes, the beach wrack was also dumped in large piles at the border of unmanaged areas, which made it additionally attractive for the birds to forage.

Consequently, birds as "cultural followers" of the managed and unmanaged sites were optimally adapted in their feeding and distancing behavior to the anthropogenic impact (→ Figure 4.3.4). More than one third of the individuals observed showed no response to mechanical activities. For some species/individuals, it was observed that they were attracted by the cleaning. Flying hunting birds such as swallows *Delichon urbica* (Hirundinidae) or ground-feeding birds like wagtails (*Motacilla* sp.) benefited from the beach cleaning and flew/walked after the machines.

The results of Denmark, Russia and Estonia are similar to our German investigations (see CONTRA-report Möller et al., 2021). In conclusion, especially for these cultural followers/synanthropic species we assume that beach wrack with the respective infauna is a less attractive food source as organic residues from human food that is far richer in fat and protein and thus higher in calorific content. In addition, for the birds this food is far easier to access e.g. from rubbish bins, which are mainly found in managed areas, as tourist numbers are also likely to be higher here.

Our findings within CONTRA also indicate the lower species richness and lower abundance of macrofauna in the managed beaches (20 vs 16 taxa, CONTRA-report Möller et al., 2021), which subsequently supports our bird observations. The macrofaunal composition was studied in more detail at two beaches of Poland: Puck represents the managed and Rzucewo the unmanaged site. The total macrofaunal abundance in the unmanaged area was almost double the values recorded at the managed station. Consequently, the unmanaged region had higher biodiversity, more taxa than the managed region. The biomass of *Hediste diversicolor* (Polychaeta) (absolutely dominant) and the bivalve representatives *Limecola balthica* and *Mya arenaria* in the unmanaged region was significantly higher than in the managed one. This results from the availability of a large amount of organic matter, which in this case provides an excellent food source as well as a possible breeding site. On the other hand, increased organic matter may cause temporary oxygen deficiency, hence the higher abundance of macrofauna in the unmanaged region is mainly due to the presence of opportunistic species that are adapted to live in adverse environmental conditions. Examples of such species, in addition to *H. diversicolor* and *L. balthica*, are insect larvae of Chironomidae and benthic Oligochaetes. The observed seasonal changes reflect the natural life cycle of individual macrobenthic components, with peaks in abundance in late spring and fall, which was observed for both areas. See CONTRA-report Möller et al., 2021 for more details.

4.4 Noise and scare effect

As already mentioned, the birds as "cultural followers" of the managed and unmanaged sites were optimally adapted in their feeding and distancing behavior to the anthropogenic impact (→ Figure

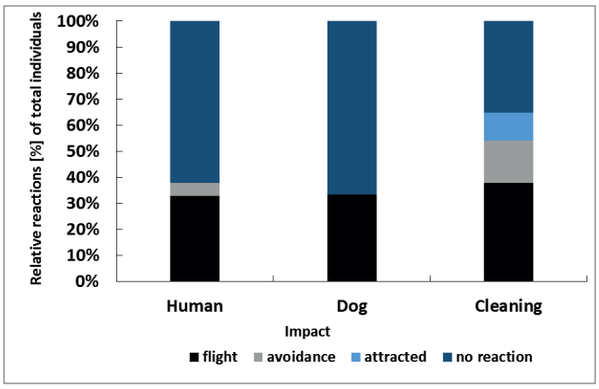


Figure 4.4.1. Responses of bird individuals (i=201) exposed to the three different effects: human(s)/walkers (i=122), dog(s) (i=42) and cleaning activities (i=37) for all study days (n=1–4) and beach sections studied (n=7, Germany).

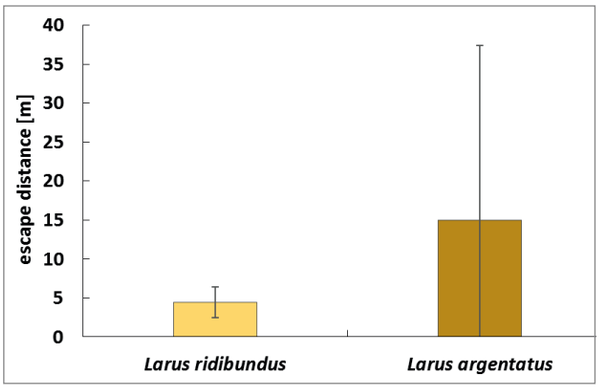


Figure 4.4.2. Mean distances [m] to German cleaning vehicles leading to escape for individuals (i=37) of the *Larus ridibundus* (i=24) and *Larus argentatus* (i=13).

4.3.4, → Figure 4..4.1). The mean escape distances of the individuals to the beach cleaning activities were determined to be 4.4 m for *L. ridibundus* (i=24) and 15 m for *L. argentatus* (i=13) (→ Figure 4.4.2). Escape reactions are associated with energy expenditure for the individual and can thus lead to reduced fitness, e.g. due to time lost during feeding or regeneration. It is therefore essential to adapt the behavior in order not to lose energy unnecessarily through avoidable escape reactions ("habituation"). Accordingly, for those birds that do not experience any negative consequences from machine beach cleaning (injury or death from the machine), the escape distance decrease. Furthermore, some species/individuals were attracted by the cleaning. According to Becker-Carus (2004), birds can learn through operant conditioning. In this case, the birds learned that food is increasingly available during beach cleaning (=positive consequence). This positively reinforced the behavior of staying near the cleaning vehicles or follow their tracks in the sand. However, noise is known qualitatively and quantitatively to affect wildlife in manifold ways. Those can include physical damage to ears, fright, flight responses, avoidance responses, altered behavior with regard to foraging, decreased ability to hear predators, all of which can negatively affect fitness and survival (Ortega, 2012). The most commonly observed response to noise is avoidance. To our knowledge, the specific effect of noise pollution from beach cleaning machinery has not been studied so far and neither how this effect relates to those from other potential sources of noise on managed beaches such as visiting tourists or nearby roads.

Our results show that besides the presence of humans, beach cleaning activities can have a direct, short-term influence on bird behavior (→ Figure 4.4.1). However, the vehicles also represent a multisensory stimulus, which means that different and complex senses of the birds were affected, e.g. the visual sense. The machines emit a certain level of sound but also the sound quantity is important, which was not possible to determine with our measuring technique. However, our studies showed that after subtracting the ambient noise, the additional noise pollution caused by the vehicles in Denmark, Germany, Russia and Estonia was between 10 up to 30 dB at the closest distance to the machines. Nevertheless, the sound pressure level is a technical and not a psychoacoustic quantity. A conclusion from sound pressure level to the perceived sensation of loudness is only possible to a very limited extent. In general, an increase or decrease in the sound pressure level tends to produce a louder or quieter perceived sound event. Above a loudness level difference of 10 dB is perceived as a doubling of loudness. However, due to the determination via diverse mobile phone microphone recordings, the short measurement duration and a non-standardised measurement technique, these data should only be understood as an approximate estimate.

5 Ecosystems services related to sandy beaches and their management

Ecosystems services are most broadly described as the benefits that people obtain from ecosystems (Burkhard et al., 2010, 2012). The assessment and mapping of ecosystem services has become an important and necessary task both in scientific research and for decision-making in policy (Müller et al., 2020). The assessment scheme is integrative and by applying the concept it is possible to pinpoint several current environmental and also societal challenges and problems.

The maintenance of ecosystem services is a priority target of the conservation of ecosystems. The main goal of valuating ecosystem services is to demonstrate the importance of a full qualitative and quantitative range of benefits that humans gain from nature and the consequences that we face in case of not protecting nature. Whether ecosystem services should be monetarized or not is highly debated (e.g. Costanza et al., 1997; Ahtiainen & Öhman, 2014). Many ecosystem goods do not have a market price or the price does not represent the total value. Therefore two concepts have been developed and can be used: 1) willingness to pay (WTP) and willingness to accept compensation (WTA), with the former being more commonly used. WTP measures the amount of money a person is willing to pay to obtain the ecosystem in a good status close to natural conditions and less impacted by humans, i.e. it measures the economic benefits from the good. WTA is the amount of money a person is willing to accept to change these ecosystem goods in a more affected status, i.e. it measures the economic losses of forgoing the good (overviewed e.g. in Ahtiainen & Öhman, 2014). Our aim within this report is to raise awareness of the multi-functionality of sandy beach ecosystems and changes that are caused by beach management. Hereby the aim is not to put a price-tag on nature features, but to use the ecosystem services valuation system in decision making to help to estimate the consequences of change and whom and how these changes affect most. Applying the ecosystem services concept in beach management strategies can guide us for a better understanding of beach ecosystems in general and for more sustainable nature conservation (Müller et al., 2020).

5.1 Various aspects and parameters of ecosystem services

Ecosystem services are divided into three different group based on whether they are provisioning, regulating or cultural services. Taking intergrity as a separate class was proposed and introduced by Müller (2005), including abiotic heterogeneity, biodiversity, biotic water flows, metabolic efficiency, energy capture, reduction of nutrient loss, storage capacity; hereby these are included under regulating and maintenance (→ Table 5.1.1). Sandy shores provide a wide range of ecosystem services, e.g. sediment storage and transport, wave dissipation and associated buffering against extreme weather events (storms), maintenance of biodiversity and genetic resources, scenic views and recreational opportunities, facilitation of functional links between terrestrial and marine environments in the coastal zone (Defeo, et al., 2009). The list and short description of ecosystem services we tackled under the CONTRA project are summarized in → table 5.1.1. In order to gain an overall better understanding of beach wrack management related ecosystem services, we present four different scenarios. All four of the scenarios were based on beach management in managed and unmanaged beaches as well as and presence-absence of beach wrack residuals (see text box for descriptions).

In total a group of 30 experts from 7 countries around the Baltic Sea was involved in the ecosystem services valuation process: Russia (8), Sweden (7), Estonia (4), Germany (3), Lithuania (3), Poland (3), Denmark (2). 17 experts were joined with the CONTRA project while 13 experts were not related to this project directly. Experts outside the

CONTRA were asked to participate based on personal contacts. Based on self-assessment the expert-group involved in evaluating ecosystems services regarding general beach management aspects had diverse background. Most expertise was noted in beach ecology followed by ecosystem services and cultural aspects and beach management (→ Figure 5.1.1).

For the question how important is the respective ecosystem service relatively for the total provision at a Baltic sandy beach, each expert was asked to score the baseline scenario according to 5 categories (1, 2, 4, 8 – accordingly: no/low importance, moderate importance, high importance, very high importance). In order to answer how the ecosystem services are affected by the change from the

Table 5.1.1. Overview of the values related to the ecosystems services on sandy beaches, based on the publication of Esther Robbe "An impact assessment of beach wrack and litter on beach ecosystem services to support coastal zone management at the Baltic Sea"" (In preparation).

		Ecosystem Services (ES)	Description
Provisioning	1	Wild plants for materials (further processing)	Beach wrack for further processing, e.g. eelgrass for insulating material (construction) or stuffing material (pillows, mattress), use of beach wrack within dune restoration. Also raw material in industry (eg cosmetics etc).
	2	Food	Beached algae and mussels for food (eg Ulva sp, Fucus sp, Rangia sp), also as raw material in food industry.
	3	Biomass as energy source	Beach wrack or other organic material for energy conversion
	4	Extraction of minerals (sand, nutrients)	Sand used for further use (construction industry), and direct application of BW to fields without further processing to utilize the nutrients and sand content (for nutrient enrichment, loosen the soil).
	5	Timber/ Driftwood	Driftwood used for further processing (handicrafts)
	6	Natural Ornaments	Collection of natural ornaments (e.g. seashells) washed ashore
Regulating and Maintenance	1	Sediment storage and transport	Beaches as sand storage and transport for natural coastal dynamics
	2	Coastal Protection/ Flood control	Attenuation of wave energy and flood prevention, e.g. inclination of beach, beach width, beach wrack.
	3	Biodiversity and habitats	Habitat and food base for several microorganisms and animals, thus including further food for higher animals (e.g. birds) and nursery ground (e.g. flies). Presence/absence of selected species.
	4	Pest and disease control	Sand and beach wrack as provider of habitat for native pest and control agents
	5	Water purification	Regulation of the chemical condition of salt waters by living processes (incl. algae, seagrass), e.g. to combat eutrophication
	6	Groundwater regulation	Groundwater regulation and maintaining water cycle (e.g. water storage and buffer)
	7	Carbon sequestration/ storage	Regulation of chemical composition of atmosphere and oceans by sequestration of carbon. Enhancing terrestrial sequestration. Including the mitigation of green house gases.
	8	Nutrient regulation	The capacity of an ecosystem to store and recycle nutrients, e.g. N, P (for beach soil and dune vegetation)
	9	Dispersal of seeds	Dispersal of seeds and the reproduction of lots of plants (resuspension by beach wrack, coastal dynamics)

		Ecosystem Services (ES)	Description
Cultural	1	Recreation and tourism (active)	Beach as recreational, touristic area (hiking, swimming sun bathing) and sports spots
	2	Recreation and health (observational)	Beach for wildlife watching and nature observation
	3	Knowledge systems	Beach ecosystem as a site to educate about nature conservation and human-nature conflicts, and as research topic (science)
	4	Culture and heritage	Beaches and their ecosystems as part of local identity and cultural heritage (historically important)
	5	Regional identity	Elements or processes of ecosystems that contribute to a person's individual identity (sense of belonging) or strengthen people's group identity.
	6	Landscape aesthetics	Inspirational experiences at beaches and their ecosystems for enjoyment of nature (natural beauty)
	7	Natural heritage	The existence value of nature and species themselves, beyond economic or human benefits

baseline scenario to scenario 1, 2 and 3, each expert had to score each scenario (1 to 3) between -3 to +3 (high decrease, medium decrease, low decrease, no impact, low increase, medium increase, high increase). Hence, this score shows the relative change or impact of each scenario compared to the baseline scenario.

The average scores given for ecosystem services indicated that when it comes to provisioning services, sandy beaches with minimal beach wrack and without management were evaluated to provide the least – that goes for e.g. food, biomass as energy resource, extraction of minerals etc. Regulating and maintenance related services were estimated a little higher by highlighting most sediment transport, coastal protection and biodiversity. On the other hand the highest importance was given to cultural aspects, especially those related to recreation and tourism, landscape aesthetics and natural heritage (→ Figure 5.1.2).

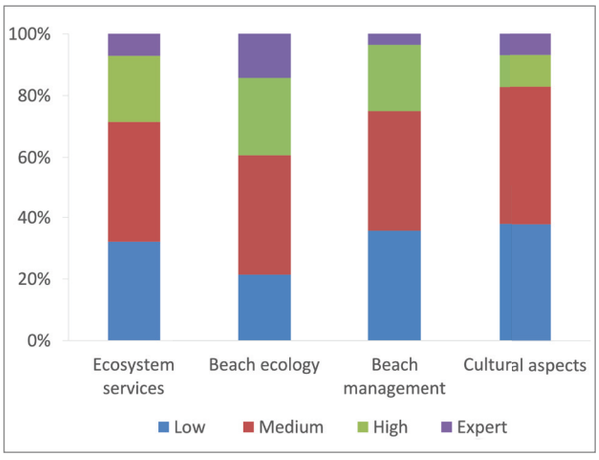


Figure 5.1.1. Level of expertise based on self-estimation in different ecosystem services related aspects regarding beach management. Low, medium, high and expert indicate the expertise level on a given thematics. Figure summarizes information from 30 experts.

The management of these natural sandy beaches (scenario 1) which are mostly devoid of beach wrack was evaluated to harm almost every ecosystem service assessed. Positive aspects of such management orientation were noted only in improving coastal protection and recreation (tourism) activities (→ Figure 5.1.4).

Regarding the baseline scenario the overall relative change in ecosystem services, where the landings of beach wrack are medium to high and no management activities exist, (scenario 2) was estimated as positive by most of the experts (→ Table 5.1.2). The presence of beach wrack was considered as a promoter of all ecosystem services except with small negative effect on the extraction of minerals and strong negative effect on tourism-related recreational activities (→ Figure 5.1.5). An increase in biodiversity and habitats and natural heritage in such ecosystems was most significant.

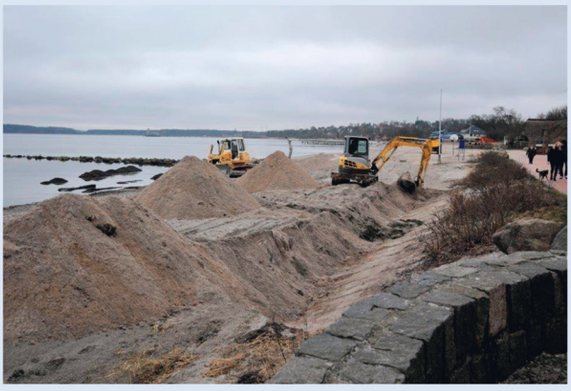
As for scenario 3 – sandy beach with medium to high beach wrack landings and with management the opinions on the effect of ecosystems services were most diverse (→ Table 5.1.2). Those who evaluated the increase in ecosystem services with



Baseline scenario:
Sandy beach with no or small beach wrack landings and without any management.
Naturally sandy beaches where the amounts of beach wrack remain negligible, however, small amounts of algae and other drifting materials (wood, marine litter etc.) will reach the beaches. No beach management activities that encompass machinery take place on the beach.



Scenario 2:
Sandy beach with medium to high beach wrack landings and without management.
Naturally sandy beaches where the amounts of beach wrack landings are medium to high. No beach management activities that encompass machinery take place on the beach.



Scenario 1:
Sandy beach with no or small beach wrack landings and with management.
Managed sandy beaches where the amounts of beach wrack remain negligible, however small amounts of algae and other drifting materials (wood, marine litter etc.) will reach the beaches. Beaches are managed mainly for coastal protection reasons (sand addition, beach nourishment, dune restoration).



Scenario 3:
Sandy beach with medium to high beach wrack landings and with management.
Naturally sandy beaches where the amounts of beach wrack landings are medium to high. Beaches are managed mainly for aesthetical reasons (e.g. beach wrack removal), but also some coastal protection measures may apply (sand addition, beach nourishment, dune restoration).

Photos: scenario 3 - © Tiina Paalme
scenario 1 – © Timmermans, W., de Jong, F., Stelljes, N., Sterr, H., Martinez, G., Harsema, H. 2019. Urban Climate Adaption. Innova Ezine. www.urbanclimateadaptation.net/ezine3-2018/

higher scores were those experts who also witness more of the suffocative nature of beach wrack in their nearby regions. Not surpisingly the strongest positive impact of beach wrack management was seen regarding the active recreation and tourism-related services (→ Figure 5.1.6). A slight increase was also noted in positive aspects of knowledge systems, culture and heritage and regional identity emphasizing that managed beaches have become a part of local culture (see CONTRA-reports of Hofmann et al., 2021ab). The evaluation also indicated a small positive change in scenario 3 due to management activities in provisioning services (e.g. increase in using wild plants for materials (further processing) or biomass as energy resource).

Table 5.1.2. The overall estimation on respective change in ecosystems services related to beach wrack amounts and management activities on sandy beaches compared to the baseline scenario (natural sandy beach with no or small amount of algae and no management) based on experts scoring. % shows the share of the experts who evaluated the given scenarios either to have a positive or negative impact on the sandy beach ecosystem compared to the baseline scenario.

	Scenario 1	Scenario 2	Scenario 3
	No or small amounts of beach wrack	Medium to high loads of beach wrack	Medium to high loads of beach wrack
	Managed	Unmanaged	Managed
Positive impact	40 %	83 %	53 %
Negative impact	60 %	17 %	47 %

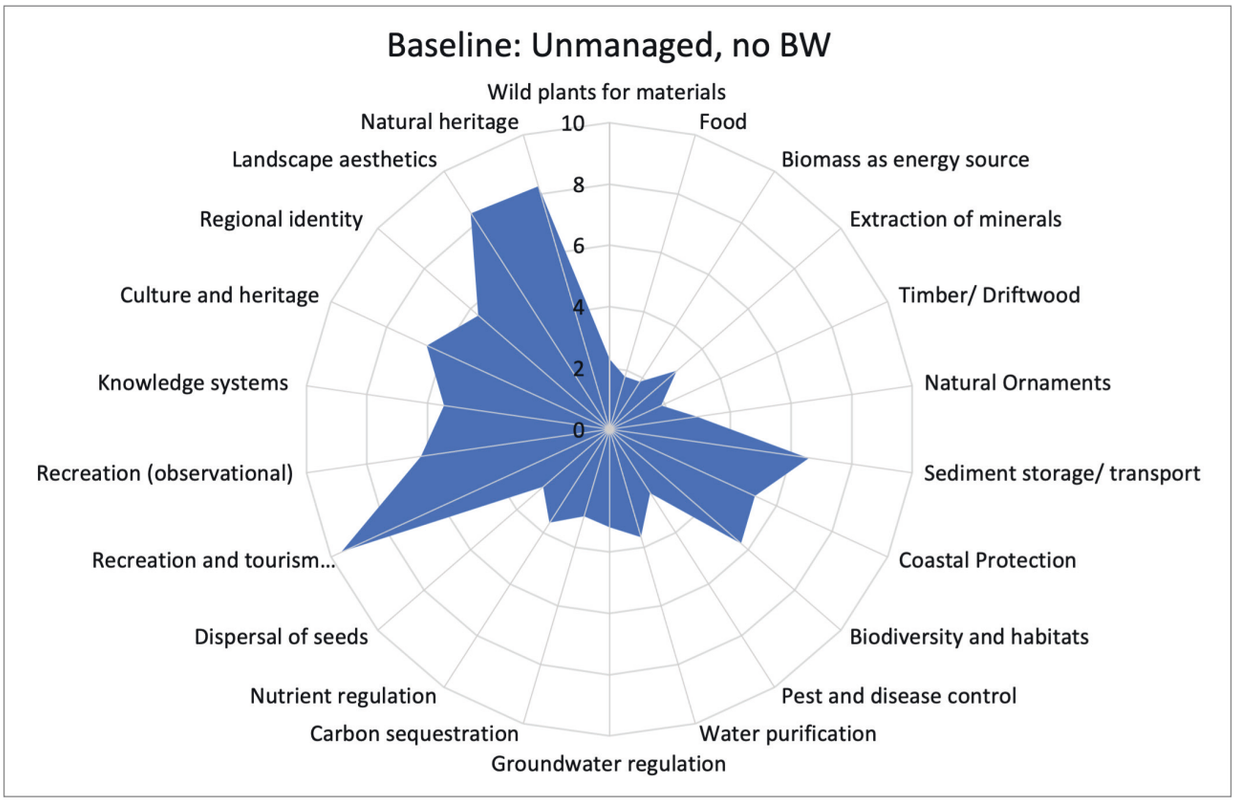


Figure 5.1.2. The relative importance (%) of ecosystem services provided by sandy beaches where the beach wrack landings are missing or minimal and no management activities exist (baseline scenario, averaged based on scoring). Numbers indicate the importance of a given service (%) (n=30).

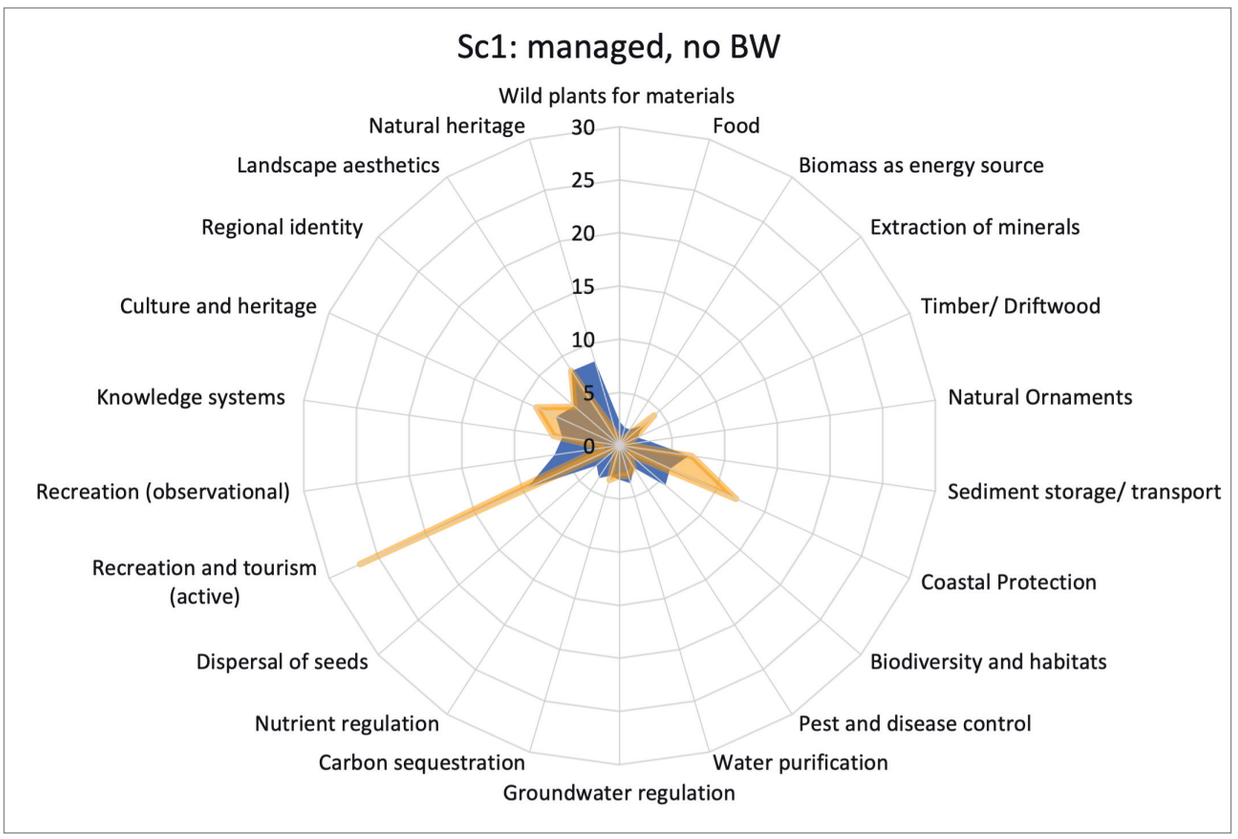


Figure 5.1.3. The relative importance (%) of ecosystem services provided by sandy beaches where the landings are missing or minimal and management activities exist (yellow) regarding the baseline scenario (blue) (n=30).

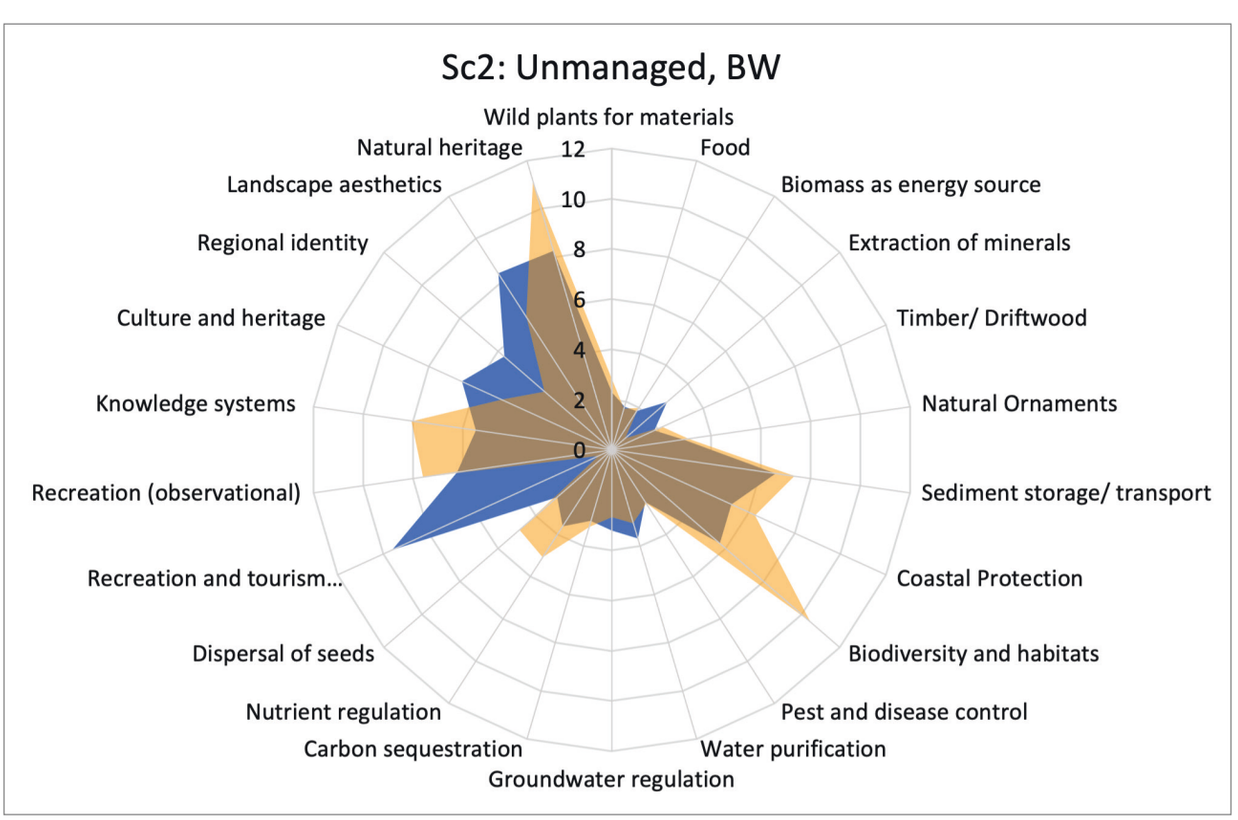


Figure 5.1.4. The relative importance (%) of ecosystem services provided by sandy beaches where the landings of beach wrack are medium to high and no management activities exist (yellow) regarding the baseline scenario (blue) (n=30).

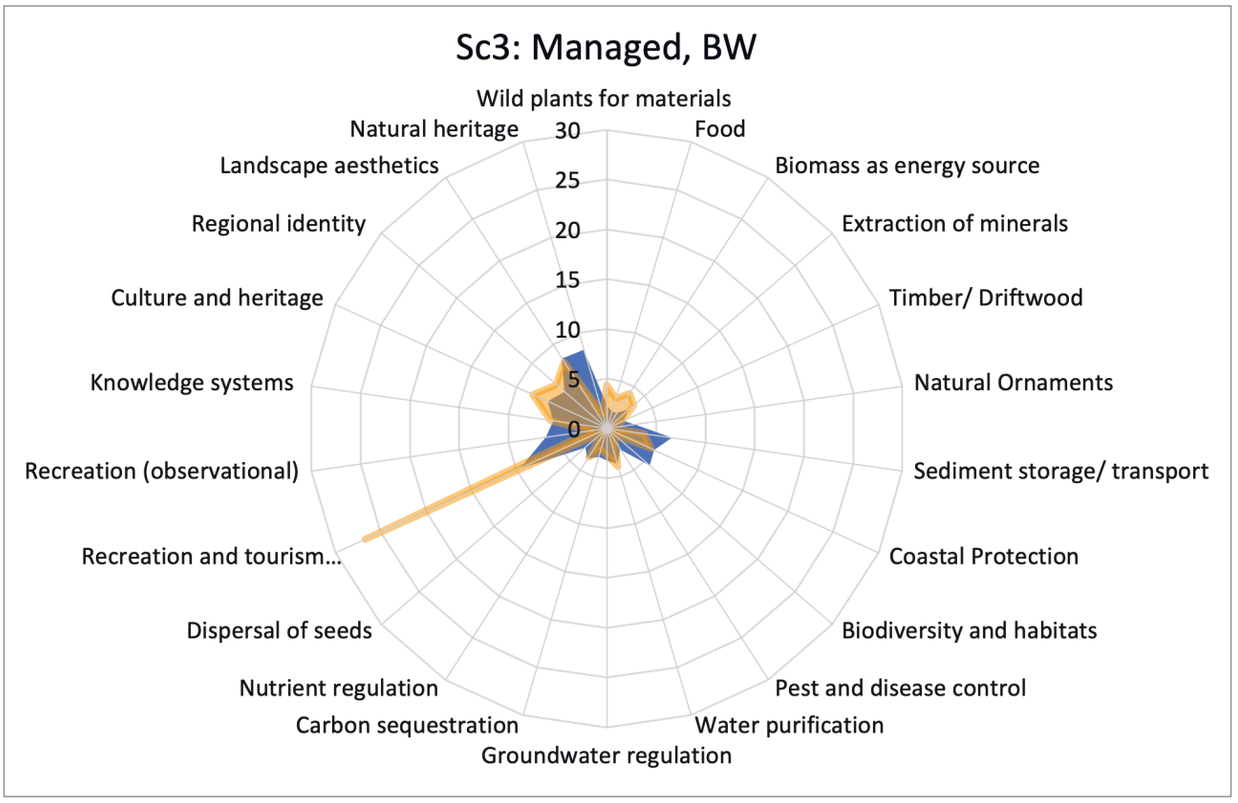


Figure 5.1.5. The relative importance (%) of ecosystem services provided by sandy beaches where the landings of beach wrack are medium to high and management activities exist (yellow) regarding the baseline scenario (blue) (n=30).

5.2 Ecosystem services in the light of the CONTRA case studies

The possibility of the overall increase of benefits that can be gained from already managed beaches has been one of the driving forces of the CONTRA project from the start. Hereby the aim has been also not to further harm or negatively impact any of the natural sandy beach ecosystem feature. Within the CONTRA project 7 case-studies were described in more detail and 2 more were shortly overviewed in order to cover a wider perspective of beach wrack uses (→ Table 5.2.1). All the case-studies except for one worked with the raw material that was collected from already managed sandy beaches: in the case of Estonian experience (production of furcellaran), the raw material was either trawled directly from the sea or collected from various types of beaches along the coastline after storm events. In addition, the case-study EELGRASS (1a) was performed separately – as hereby the main focus was the pure material collection (*Zostera marina*) from the beaches mostly by hand. For a more detailed overview of different approaches of beach wrack collection and treatment see the CONTRA report Chubarenko et al., 2021.

In → Table 5.2.2 we summarized the relative effect of the case-study based management effort on ecosystems services that are provided by managed sandy beaches. As mentioned earlier, the typical managed beach with removed beach wrack was seen as strongly biased towards only one ecosystem service "tourism-oriented recreation activities" (→ Figure 5.1.5, → Table 5.2.2). However, with a proper and targeted beach wrack management it is possible to gain more value from different ecosystems services (→ Table 5.2.2). For example 6 out of 9 approaches presented in the CONTRA report of Chubarenko et al., (2021) were estimated to contribute into a better use of provisioning services. Hence, beach wrack was used as raw material for soil/compost production (e.g. Wrack4Soil, EELGRASS, FERTIWRACK), or used to meet the special interests in food industry (furcellaran production from the red algae *F. lumbricalis*) or as an energy resource (BWC, ALREA). FERTIWRACK was geared on nutrient cycling as the main aim was the production of beach wrack compost – this can be done e.g. by using reed bed treatment and thus having more control over the decomposition process at the beach and thus causing less harm for

Table 5.2.1. Overview of the case-studies addressed under the CONTRA project. For further details see CONTRA reports Chubarenko et al., 2021 and Almquist et al., 2021 (economical aspects).

Case study nr	Name	Abbrevation	Area	Country
1	Beach wrack-based soil production	Wrack4Soil	Bad Doberan/ Poel	Germany
1a	Collection of pure eelgrass	EELGRASS	Bad Doberan/ Poel	Germany
2	Bio-coal from beach wrack	BWC	Island Rügen	Germany
3	Beach wrack as a compost material in landfill bio-covers	Wracover	Koge Bay	Denmark
4	Beach wrack applicability for dune restoration measures	Wrack4Coast	Kaliningrad Oblast	Russia
5	Beach wrack thermal recovery and relevant analytical performances	ALREA	Kalmar	Sweden
6a	Nutrient and pollutant flux to coastal zone originating from decaying beach wrack on beaches	WAIT	Puck Bay	Poland
6b	Beach wrack treatment in a reed bed system	FERTIWRACK	Swarzewo	Poland
Estonian experience	Production of furcellaran both from trawled and beached algae *Furcellaria lumbricalis*	ESTAGAR	Saaremaa	Estonia

the environment in general. The nutrients that are removed together with beach wrack were available for terrestrial plants within the reed bed and thus the leakage back to the marine environment was also smaller. Furthermore, due to the biocovering within the Wracover study it was possible to mitigate methane emissions. In addition – native beach plants were planted the top of the biocover and this kind of activities also contribute into increasing local biodiversity and habitats and also landscape aesthetics. The case study BWC was estimated to contribute partly to carbon neutral solutions – by removing the beach wrack and using this as an alternative source of energy (instead of burning fuel or wood).

The case study Wrack4Coast investigated dune restoration possibilities and thus improving natural coastal protection. These kinds of activities are mainly regarded as restoring the natural environment and thus showing the highest increase in ecosystems services such as e.g. for biodiversity and habitats, sediment storage and transport regulation was estimated.

Responsible beach management with minimal ecosystem harm and proper recycling of beach wrack after removal can significantly enhance regional identity perception e.g. the locals (municipality) produce something useful from beach wrack which is usually regarded as a nuisance/waste. Consequently, the image-building of municipality's/company's activities might further increase the self-pride perception of the local community. In times of increasing awareness of climate change and environmental protection issues it may make a tourist beach/region more attractive for a specific target group of tourist (tourist with focus/preferences on environmental sustainability).

Table 5.2.2. The relative importance (RI) of ecosystems services in managed beaches with medium to high loads of beach wrack (scenario 3) with a general indication of how the further treatment of beach wrack can contribute to the importance of various ecosystem services. Stars (*) are indicative, respectively: * small increase in ES, ** medium increase in ES, *** a significant increase in ES.

Ecosystem Services (ES)	Managed beach with beach wrack, RI (%)	Wrack4Soil	EELGRASS	BWC	Wracover	Wrack4Coast	ALREA	WAIT	FERTIWRACK	ESTAGAR
Wild plants for materials (further processing)	4.4	***	***						*	*
Food	3.1									*
Biomass as energy source	4.2			***			***		*	
Extraction of minerals (sand, nutrients)	3.6									
Timber/ Driftwood	1.7									
Natural Ornaments	0.6									
Sediment storage and transport	3.8					**				
Coastal Protection/ Flood control	4.9					***			*	
Biodiversity and habitats	0.9				*	***			**	
Pest and disease control	1.5								*	
Water purification	4.0					*		*	*	
Groundwater regulation	2.7					*				
Carbon sequestrian/storage	2.2	*	*	*	**	**				
Nutrient regulation	3.4	*	*		*	**		*	**	
Dispersal of seeds	0.6				*	*			*	
Recreation and tourism (active)	26.7					*				
Recreation and health (observational)	1.7					**			**	
Knowledge systems	5.7				*	*		***	*	
Culture and heritage	8.2					*				*
Regional identity	6.7	*	*		*	*				*
Landscape aesthetics	8.0				*	*			*	
Natural heritage	1.5					*				

6 Summary and recommendations



Tourism-oriented beach management is not an easy task as there are several aspects that need to be taken into account, just to name a few: bathing water quality, local waste management, beach cleaning procedures, safety, specific beach ecosystem characteristics, environmental status, beach infrastucture (shops, parking space etc.), spatio-temporal variability in beach use etc. For the municipalities one source of information is e.g. the Blue Flag Program (www.blueflag.global). This program started in 1987 in France and for now it is established as a worldwide programme promoting sound environmental education and sustainable management of beaches, marinas and boating operators. In total the program is followed in 47 countries covering over 4600 different sites. Consequently, the iconic Blue Flag is a globally well-known voluntary award. In order to qualify for the Blue Flag, a series of strict environmental, educational, safety, and accessibility criteria must be met and continuously maintained. Regarding countries who participated in the CONTRA project the number of Blue Flag beaches at the Baltic Sea is as follows: Denmark 174, Germany 44, Poland 25, Sweden 7, Estonia 3 and Russia (Kaliningrad) 2.

The amount of beach wrack is certainly one of the central questions in beach management perfomance. Regarding the presence of beach wrack the Blue Flag Program (www.blueflag.global/) suggests under the environmental management section as follows: "Algal vegetation or natural debris must be left on the beach (criteria 16)". *„Algal vegetation is generally accepted as referring to seaweed. Seaweed and other vegetation/natural debris are natural components of both freshwater and marine ecosystems. These ecosystems must be considered as living and natural environments and not only as a recreational asset to be kept tidy. Thus, the management of seaweed or other vegetation/natural detritus on the shore should be sensitive to both visitor needs and biodiversity. Natural disposal by tides and waves at the beach is accepted, as long as it does not create a nuisance.*" The acceptance level is highly dependent on the general knowledge of beach ecosystems functioning. Both CONTRA-reports of Hofmann et al., (2021ab) provide more detailed overview of the public acceptance tolerance regarding the amount of beach wrack on the beaches both in touristic high- and low season.

In this chapter we present some suggestions/aspects that should be taken into account in beach management planning and organizing from the environmental point of view. As there is great variability in beaches ecosystems and beach uses across the Baltic Sea region, then it is always advisable for municipalities to invest in the research of local beach ecosystem functioning before introducing/updating the respective beach management activities. Beach management should among other things include the fact that for some beaches the wrack can be an important feature for coastal protection e.g. as wave inhibitor or significant source of nutrients for dune vegetation. However, for some beaches, seasonal beach clean-up planning can help partially avoid conflicts of interest between environmental issues and tourism industry. It is most important to keep in mind that beach wrack is a natural part of beach ecosystems and if it has not turned into an excessive nuisance, less management of beach wrack provides more values for the local environment.

Accumulation of beach wrack

In the Baltic Sea, beach wrack accumulation is most intensive in the late autumn, winter and early spring seasons, and considerably lower in summer. The beach wrack accumulation pattern is related to increased storm activity in the autumn-winter period and natural cycle of seagrass/macroalgae growth. Species composition of the beach wrack varies over different seasons.

Amounts of beach wrack

The amounts of beach wrack that land on different regions of the Baltic Sea coastal areas vary significantly. Thus it is difficult to give ubiquitious suggestions, different strategies can be applied based on beach wrack amounts and residence time.



However, it could be helpful to agree upon a maximum amount of beach wrack on the beaches that is acceptable to the wider public and does not need removing. For example, there is no need for beach wrack removal if the new wrack (wrack deposited near waterline) covers the beach less than e.g. 10 % (see CONTRA-report Hoffmann et al., 2021b) and for old wrack these % can be a bit higher depending on the actual volume of the beach wrack.

Beach wrack species composition

The interest in blue economy is growing and thus there is also growing interest in pure algal material, e.g. with focus on one concrete species or algal group (see CONTRA-report Chubarenko et al., 2021 about collecting eelgrass *Zostera marina* and red algae *Furcellaria lumbricalis*). The proportion of filamentous algae increases up to 85–90 % in new wrack near water line in summer. Beach wrack, which consists of filamentous macroalgae, has a rather dense, consolidated structure as the algae are sticked together. Thus the aeolian dispersal of such a wrack is lower and its significance for the fertilisation of the terrestrial beach vegetation is reduced. Hence, filamentous algae are only found very rarely in the vegetation zone of the dunes or inland. At the same time the degradation rate of filamentous algae both in the swash zone and in the water is much quicker when compared to perennial algae or seagrass.

However, it is recommended that more attention is paid to the species composition of beach wrack over the course of the year. Hence, giving more focus to the species that dominate in beach wrack does not need to serve only the interests of manufacturing enterprises – it can also be useful information regarding nature tourism, education and general knowledge increase in the understanding of beach ecosystems.

Residence time

It is recommended to take into account the peculiarities of the wrack residence time on respective beaches to plan management activities. Short residence time can be a limiting factor when the aim is a long lasting beach wrack removal (e.g. beaches in Kaliningrad). To improve efficiency, it is necessary to apply special measures in such conditions. For

example, a possible optimization solution could be use of webcam observations on potentially profitable seashore to coordinate the harvesting activities. At the same time, for beaches with a naturally long-term wrack residence time (e.g. sheltered beaches in Estonia and Sweden), it might be an important component of the terrestrial ecosystems, for example, as a source of nutrients or food for beach flora/fauna. In conclusion, the combination of the three factors residence time, amounts and composition of beach wrack must be taken into account during planning management and local conservational needs.

Hazardous substances

In certain areas, a proportion of the wrack moving onshore is permanently trapped. This creates problems not only for inhabitants of those areas and local authorities, who are responsible to maintain the beaches, but also for the local beach ecosystem. Research under the CONTRA project proved that the beach wrack can release contaminants accumulated by algae during their lifetime from seawater and sediments. Moreover, mercury studies indicated that beach wrack deposited on beaches continues to accumulate dissolved substances from seawater. Contaminants are being released to the coastal zone during decomposition of organic matter, partly to groundwaters, which are returning to the sea, and partly to the atmosphere via volatiles. Moreover, the presence of large quantities of organic matter, and the fact, that contaminants were already absorbed by marine plants and algae, results in enhanced bioavailability of contaminants, as compared to seawater where they came from. The process itself is cyclic – contaminants are being removed from seawater and sediments by marine plants and algae, in areas located at considerable distance from the coastal zone. In the case of the Puck Bay (Poland), this included the entire bay and Gulf of Gdańsk. Then they are washed ashore in several locations, building up the metal and organic contaminants pool in these spots. During decomposition, bioavailable forms of contaminants are released to the coastal zone, where biota can absorb those and transfer them to the foodchain. Breaking this link, by removal of beachcast after deposition, can result in the depuration of the ecosystem. However, this accumulation of hazardous substances seems to be strongly dependent on the areas and species composition/amounts of macroalgae and needs further research.

Litter on the beaches

Based on a survey described in the CONTRA-report of Hofmann et al., (2021a), one third of the municipalities (8 out of 23) had no information regarding the amount and kind of litter within the beach cast. This indicates clearly that on the municipality level the information regarding different aspects of beach management is often lacking. However, the amount of litter both within the organic biomass and sediment should be monitored on a local basis and taken into account when searching for further use possibilities of removed beach wrack – in other words: among other aspects the amount and nature of litter significantly affect the treatment options and possible further use of beach wrack.

From the beaches the litter can be removed separately or together with beach wrack. Most of the litter on the beaches originates from land-based activities, but the general marine pollution cannot be ignored here and litter may be carried to the beach from adjacent areas as well. There is also great variety in litter items regarding e.g. material, hazardousness, size, origin. Consequently, the presence of litter just makes the beach wrack a more complicated material for futher processing. When big and visible litter items can be removed easily by hand-picking, then the smaller items that are entangled or buried into the beached algal material are harder, if not impossible, to find and remove. Microlitter (litter items in size < 5 mm) and nanolitter (generally litter items in size < 0.001 mm) surveys within the beach wrack need more specific approach.

Microplastic pollution is raising public concern globally and the presence of it within beach sand and beach wrack limits the direct use of removed beach wrack. For example, it is not advisable to use it in agricultural lands as fertilizer as the consequences of microplastic pollution in the agricultural fields for sustainability and security of food production are currently unknown. This thematic is rather new and might become a relevant topic for agricultural environmental policies in the future (Henseler et al., 2019).

Littering of dunes is another aspect that needs more attention. For example, in the Mediterranean region a clear increase of litter cover along the sea-inland gradient has been described with foredunes and pine forests having the highest cover of litter (Šilc et al., 2018) of which most frequent were plastic, polystyrene and glass. At the same time dunes are often very fragile to mechanical disturbance (both by foot and machines). In conclusion,

in beach management and cleaning it is important to have a wider view on the whole beach ecosystem and prevent beach littering in the first place and also prevent the moving of beach litter (back) towards inland and marine environment.

Management period

Common practice is that beaches are managed in the touristic high-season from May to August and left untouched for the rest of the year. However, based on a survey carried out within 43 municipalities, the active beach management in some regions takes place all year around (CONTRA-report Hofmann et al., 2021a). E.g. there are some regions in Sweden, which especially suffer from extreme loads of beach wrack (mainly filamentous algae) and remove wrack mostly in November-December and April-May as the removal needs low water levels in a shallow bay. Hence, extra removal activities after storms with large amounts of wrack landings were performed additionally. It has been suggested that in areas, where the water quality on a local level is problematic, it is possible to improve the water quality with a more targeted beach management (CONTRA-report Chubarenko et al., 2021).

As for the regions where beach wrack landings in the low tourism season are less annoying and the recreational beach activities (e.g. walking, nature observations etc) are not severely affected, it is not advisable to carry out cleaning activities during the full year. Thus cleaning should therefore be limited to the time when there is really an increased demand for it. However, in these regions, it is suggested additionally to invest into activities related to raising public awareness regarding the importance of beach wrack as a natural part of beach ecosystems.

Management disturbance on beach ecology

Managed beaches are wider than the natural ones, have much less vegetation, lower biodiversity, fewer „natural" dunes and much flatter topographic features than unmanaged beaches. According to various studies summarized in a review by Defeo et al., (2009), the beach wrack cover of the beach and the abundance of shorebirds were positively correlated. In addition, the general loss of dune vegetation contributes to increased nestling mortality of dune nesting bird species (Watson et al., 1996). In our studies the absence of beach cleaning was not associated with a significant increase in biodiversity of bird species and numbers of individuals on unmanaged beaches. Both managed and unmanaged beaches in Germany were dominated by two species of seagulls which are possibly more attracted to organic residues from human food compared to infauna within beach wrack. Hence, the highest bird individual presence was determined in total in the reference area (bird sanctuary) that reflected the "real" natural situation (higher biodiversity and possibly less sand compaction). In already heavily impacted sand beaches in Germany the anthropogenic effects such as landscape change/development and massive human presence already lead to a flora and fauna reduction in biodiversity and beach cleaning deepens the effect.

The birds as "cultural followers" (e.g. seagulls) of the managed and unmanaged sites were optimally adapted in their feeding and distancing behavior to the anthropogenic impact. One third of the individuals observed showed no response while 13 % of the birds were attracted to mechanical cleaning. At the same time, over half of the birds avoided or flew away during the cleaning activities.

Animal communities inhabiting sandy beaches rely heavily on seaborne inputs of carbon and organic materials since *in situ* productivity is very low (Brown & McLachlan, 1990). Beach wrack, thereby, constitutes the major allochthonous subsidy for these ecosystems. Hence, its frequent removal can affect the productivity and standing crop of primary and secondary consumers in beach inhabiting communities. Indeed, numerous studies found that the removal of beach wrack led to a decrease in diversity, abundance, total biomass of beach inhabiting macrofauna. Based on our findings within the CONTRA, the total macrofaunal abundance in the unmanaged area was almost double the values recorded at the managed site. The unmanaged region had higher biodiversity, more taxa than the managed region. Due to the negative impact of the removal of beach wrack on local biodiversity, there is a necessity to consider if the beach wrack can be partly left untouched.

On the other hand, increased organic matter may cause temporary oxygen deficiency in deeper layers under thicker beach wrack biomass and/or sediments, hence the higher abundance of macro- and meiofauna in the unmanaged region is mainly due to the presence of opportunistic species that are adapted to live in adverse environmental conditions. The fact of less oxygen in pore waters directly affects the abundance of meiofauna, the organisms that live in the spaces between sand grains. It was shown that meiofauna, living in pore waters with lower oxygenation than the water column,

are more sensitive to environmental disturbances than macrofauna. The studies carried out under the CONTRA project showed that the mean meiofauna abundance in the managed area was almost three times higher than that in the unmanaged site, and taxa considered sensitive to oxygen lack were found mainly in the managed area.

Sand content

One important aspect regarding beach wrack removal is also removal of sand from the beach ecosystems. The sand content within beach wrack varies greatly, based on our studies in Kakumäe, Estonia, the sand content in removed beach wrack was on average 58 % with maximum values of 97 %. In our study it equaled to average of 2.5 kg of sand (dry weight) per 1 m^2 that was removed together with beach wrack from new wrack line and to 4.1 kg of sand on avareage per old wrack line. The maximum values reached up to 21.8 kg of sand removal per m^2. The high content of sand within the beach wrack is one argument in favor of shortening the management period and intensity. This removes valuable sand from the beach, which, in addition to the loss of surface area, plays an important role in coastal protection.

Machinery for beach wrack removal

Whenever possible (depending on the cleanable beach area and beach wrack loads) the beach wrack should be removed by hand (rake) and/or using specially developed no-motorized carts. Surely this can be done in areas where the beach wrack loads are rather low and the managed area is also small. For example the Kuressaare beach in Saaremaa, Estonia, where a 400 m long beach section is managed daily by hand and according to needs in period April-October. In areas where such approach is not applicable, mostly tractors built for agricultural activities are used. However, when using heavy machinery, it is important to really adapt the cleaning activities to the needs and to limit the number, distances and time spent travelling back and forth. The machines should be in good order and e.g. oil leaks/droppings should be prevented in the first place. Furthermore, when using rakes, it is important not to let them penetrate too deeply into the soil (not deeper than 10 cm) to avoid the constant rearrangement of deeper sediment layers. As this is where most of the material lies, the main cleaning is commonly done in the splash zone. However, as this zone is the most fragile part of the beach ecosystem, travelling and cleanings should be kept to a minimum.

Moving the beach wrack – to where?

The common practices of beach wrack removal include pushing the beach wrack back into the water or collecting it into piles nearby the managed beach. In case of such practice especially case-studies Wracover, Wrack4Coast and FERTIWRACK (CONTRA-report Chubarenko et al., 2021) show another approaches for the possible use of beach wrack. When piling up biomass on the beach for storage, care should be taken to ensure that these piles are not too high and, if necessary, aerated/remixed to prevent anoxic conditions and thus increased emissions of e.g. green house gases. Furthermore, it would be advisable to observe the water leaking out after raining. In principle, large quantities of biomass layered on top of each other should be avoided for long periods.

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Thomas Busk	Denmark	University of Southern Denmark	Ecology	yes
Reimo Rivis	Estonia	University of Tallinn	Geology	no
Georg Martin	Estonia	University of Tartu	Benthic ecology	yes
Kaire Torn	Estonia	University of Tartu	Marine biology	yes
Tiia Möller	Estonia	University of Tartu	Marine biology	yes
Mareike Hannes	Germany	REM Consult	Urban planning	yes
Hendrik Schubert	Germany	Rostock University	Marine ecology	yes
Jana Woelfel	Germany	Rostock University	Marine ecology	yes
Diana Vaiciute	Lithuania	Klaipeda University	Ecology	no
Marija Katarzyte	Lithuania	Klaipeda University	Ecology	no
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Aleksey Grave	Russia	Shirshov Institute of Oceanology of Russian Academy of Sciences	Engineering	yes

Name	Country	Authority	Background	Involvement in CONTRA
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Ekaterina Zhelezova	Russia	Shirshov Institute of Oceanology of Russian Academy of Sciences	Coastal systems	no
Julia Gorbunova	Russia	Shirshov Institute of Oceanology of Russian Academy of Sciences	Aquatic ecology	yes
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Laura Ferrrans	Sweden	Linnaeus University	Environmental engineering	no
Varvara Sachpazidou	Sweden	Linnaeus University	Aquatic ecology	yes
William Hogland	Sweden	Linnaeus University	Environmental science	yes
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Kristin Bertilius	Sweden	Municipality of Borgholm	Wetland biology	no
Frank Schmieder	Sweden	Swedish University of Agricultural Sciences	Biochemistry	no
Gunnar Cervin	Sweden	University of Gothenburg	Marine botany	no

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Identification of national, regional and EU regulations with respect to beach wrack

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Most of the existing national legislation of the EU member states does not cover the specific issue of beach wrack. This issue may however be incorporated into existing policies of the national legislation e.g. those that deal with aquatic resources and renewable biological resources, tackling collection, storage, processing of organic material into chemicals, fertilizers or biofuels, as well as their marketing, depending on the intended and practical use of beach wrack after collection. These belong to different policy areas and are implemented through different legal instruments.

This document provides a non-exhaustive list of regulations on EU, national and regional level that govern beach wrack removal, collection and processing.

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Denmark

Competent authorities responsible for marine and coastal environment

Danish Ministry of Environment (Miljøministeriet)[1] is the main authority that administers environmental policy and it is responsible for drafting environmental law. There are four agencies under the Ministry of the Environment:

- **Danish Environmental Protection Agency (Mijøstyrelsen)**[2] prepares legislation and guidelines and grants authorisations in several areas. Further duties include the monitoring of chemicals and offshore platforms.
- **Danish Geodata Agency (Geodatastyrelsen)**[3] is responsible for conducting geographic and hydrographic surveys. This includes responsibility for the sale and distribution of marine data and products concerning Denmark and Greenland.
- **Danish Nature Agency (Naturstyrelsen)**[4] manages tasks in forests, natural areas and along the shores of Denmark.
- **Danish Coastal Authority (Kystdirektoratet)**[5] works within the coastal area in Denmark. It analyses coasts throughout Denmark and secures the technical knowledge concerning coastal dynamics and coastal protection. The Danish Coastal Authority manages functional and regulatory tasks concerning coastal protection, dune conservation, beach protection and the Danish state's sovereignty over territorial waters.

The municipalities are responsible for granting permits and inspection of smaller enterprises. Municipalities are the regulating authority on environmental legislation. The municipalities are typically the point of contact for the general public concerning regulations.

Environmental policy relevant to the issue of beach wrack

The Environmental Protection Act (Bekendtgørelseaflov om miljøbeskyttelse LBK nr. 879 af 26.06.2010)[6]

- It is the main environmental law in Denmark. The EPA sets out the fundamental environmental protection objectives and the means by which to meet these objectives.
- The EPA aims to reduce and combat pollution, including water pollution**.**
- Waste management is regulated by Chapter 5 of the EPA and the Executive Order on Waste[7].
- The act sets a coastal protection line, which ensures that no changes are made to the Danish coast within 300 meters of the water's edge.

The Act on Marine Environment Protection (Bekendtgørelseaflov om beskyttelseafhavmiljøet LBK nr 1033 af 4.09.2017)[8]

- The Act sets regulations for the protection of the marine environment in order to restrict and prevent marine pollution.

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[1] https://mim.dk/
[2] https://eng.mst.dk/
[3] https://eng.gst.dk/
[4] https://eng.naturstyrelsen.dk/
[5] https://kyst.dk/english/
[6] https://www.retsinformation.dk/eli/lta/2010/879
[7] https://www.retsinformation.dk/eli/lta/2006/1634
[8] https://www.retsinformation.dk/eli/lta/2017/1033

Act on environmental goals for water bodies and the conservation of internationally protected areas (Bekendtgørelse af lov om miljømål m.v. for vandforekomster og internationale naturbeskyttelsesområder LBK nr 1756 af 22.12.2006)[9]

- The provisions of the EU Water Framework Directive have been transposed into Danish law by the Environmental Objectives Act, which describes the work and planning process to be implemented in order to achieve the objective.
- The act aims to establish a framework for the protection of surface water and groundwater, as well as its planning within the environment internationally protected areas.

Fisheries Act (Bekendtgørelse af lov om fiskeri og fiskeopdræt 27. 12.2018)[10]

- Regulates the management, control and development of fisheries and aquatic resources in Denmark.
- The Act sets regulations on the management of fisheries with the purposes of protection of living resources in marine- and fresh-water and for the protection of other marine animals and plants, to safeguard commercial fishing and related commercial activities.

Estonia

Competent regulatory authorities responsible for marine and coastal environment

Estonian Ministry of Environment (Keskkonnaministeerium)[11] responsibilities include organizing national environmental and nature protection, organising the use, protection, re-production and accounting for natural resources, environmental supervision, nature and marine research, geological, cartographic and geodetic operations, organising the use of external tools for environmental protection, as well as compiling strategic documents and draft legislation. The Ministry is responsible for the process of development and amendment to the legislation.

The Environmental Board (Keskkonnaamet)[12] is an administrative unit under the Ministry of Environment which coordinates and executes supervision regarding the use of natural resources and the protection of the environment by applying the state´s coercive measures on the basis and to the extent specified by law. It deals with environmental licensing, environmental violations and also carries out investigations in criminal cases.

The Estonian Environment Agency (Keskkonnaagentuur)[13] is an administrative unit under the Ministry of Environment responsible for the management and implementation of the national environmental monitoring program, environmental data collection and data management, as well as international reporting obligations.

Geological Survey of Estonia (Geoloogiateenistus)[14] is a national authority administered by the Ministry of Economic Affairs and Communications. Its task is to conduct geological research

[9] https://www.retsinformation.dk/eli/lta/2006/1756
[10] https://www.ecolex.org/details/legislation/fisheries-act-no-372-of-2006-lex-faoc026268/
[11] https://www.envir.ee/et
[12] https://www.keskkonnaamet.ee/et
[13] https://www.keskkonnaagentuur.ee/
[14] https://www.egt.ee/et

and exploration, preserving and providing geological information, advising governmental agencies and informing the public.

All local issues regarding the coastal environment are resolved and regulated by **local municipalities**, which operate independently in accordance with law. The main tasks of the local authorities are stated in the Local Government Organisation Act.

Environmental policy relevant to the issue of beach wrack

Fishing Act (Kalapüügiseadus 01.07.2015)[15]

- Main purpose of this act is to ensure conservation and economic use of fish and aquatic plant resources on the basis of internationally recognized principles of ecosystem-based fisheries.
- The Fishing act ***inter alia*** regulates commercial aquatic plant collection from the sea. Furthermore, it also specifically mentions ownership of ***Furcellaria lumbricalis*** washed ashore. Pursuant to §4(3) "***F.lumbricalis*** in the sea is in the ownership of the state. ***F.lumbricalis*** washed ashore is in the ownership of the owner of the immovable property located on the shore." Private owned beach maintenance is the responsibility of the landowner. To pick up beach wrack from the private owned beach one needs approval of the owner. Otherwise, shores are managed by local authorities who organize cleaning and maintenance of recreational beaches and who grant permit for beach wrack gathering.

Nature Conservation Act (Looduskaitse seadus 10.05.2004)[16]

- The purpose of this Act is to protect the natural environment, preserve biodiversity and natural environment of cultural or esthetical value, and promote the sustainable use of natural resources.
- This act also protects shores and banks, prohibiting activities like e.g. driving a power-driven vehicle outside designated roads on the seashores up to 200 m from water boundary However, the act permits to drive vehicles ***inter alia*** for collecting reed and gathering seaweed pursuant to §37(3).
- Pursuant to §30(4) The act permits by the protection rules to gather reed and seaweed in the conservation zone as one of the activities necessary for the preservation of the object or activities that do not harm the object. Case in point, Protection rules of Prangli Landscape conservation area (Prangli maastikukaitseala kaitse-eeskiri)[17] permit to gather reed and bladder wrack from the shore in the conservation zone of the area.

Apart from the Fishing act and Nature Conservation act a number of legislative texts could be relevant to address the issue of beach wrack. These include Water act, Waste act, and Circular Economy Strategy, among others.

Waste Act (Jäätmeseadus 01.05.2004)[18]

- This Act provides the organisation of waste management, requirements for preventing waste generation, the health and environmental hazards arising from waste, including

[15] https://www.riigiteataja.ee/en/eli/510012019009/consolide
[16] https://www.riigiteataja.ee/en/eli/515052020006/consolide
[17] https://www.riigiteataja.ee/akt/109102018002
[18] https://www.riigiteataja.ee/en/eli/507022020001/consolide

measures for improving the efficiency of the use of natural resources and reducing the adverse impacts of such use, as well as liability for violation of the established requirements.

- The Waste Act potentially provides an adequate framework to deal with beach wrack, however it does not specifically target beach wrack at the moment. Pursuant to § 5 "Biodegradable waste" means any waste that is capable of undergoing anaerobic or aerobic decomposition, e.g. food waste. However, the act further specifies that "bio-waste" means the following biodegradable waste: 1) garden and park waste; 2) food and kitchen waste from households, retail premises and caterers; 3) waste from food processing plants the composition and nature of which is similar to the waste specified in clause 2). Thus, although the act specifies biodegradable waste, it mostly focuses on terrestrial anthropogenic waste but does not refer to organic waste originating from the sea.
- Requirements for composting biodegradable waste specifically include ***inter alia*** waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing, but do not address beach wrack.

General Part of the Environmental Code Act (Keskkonnaseadustiku üldosa 01.08.2014)[19]

- The purpose of this act is to ensure good state of the environment, promote sustainable development, preserve and protect the environment, human health, well-being, property and cultural heritage.
- This act does not specifically include beach wrack. However, beach wrack could potentially fall under paragraphs 34 and 37. Pursuant to § 34, berries, mushrooms and nuts growing freely in the wild, fallen branches and other similar natural products may be picked on a plot of land belonging to another person, unless otherwise prescribed by the owner. Additionally, § 37(1) states that the public use of a water body means bathing, water sports, moving on water and ice, fishing, water extraction and other use of the water body that does not qualify as the special use of water under the Water Act.

Water Act (Veeseadus 01.12.2019)[20]

- The task of this act is to ensure protection of inland, transboundary and groundwater resources in the long term. The Water Act regulates the use and protection of water, waterbodies and their shores, the relations between landowners and water users.
- Water act sets out water protection zone of banks or shores which extends to 20 m from the baseline for the Baltic Sea. It further restricts activities in this water protection zone, prohibiting ***inter alia*** activities degrading the soil.
- Pursuant to § 72, the Marine strategy is drawn up for the entire Estonian marine area in order to achieve and maintain good environmental status (GES) of the Estonian marine area. The Marine strategy does not address the shores with the exception of requirements regarding anthropogenic marine litter washed ashore.

Act on Environmental Fees (Keskkonnatasude seadus 01.01.2006)[21]

- Provides the grounds for determining the natural resource charges, the rates of the pollution charge, the procedure for calculation and payment thereof, and the grounds and specific purposes for using state budget revenue obtained from environmental use.

[19] https://www.riigiteataja.ee/en/eli/509012020005/consolide
[20] https://www.riigiteataja.ee/en/eli/511052020001/consolide
[21] https://www.riigiteataja.ee/en/eli/515072020006/consolide

Germany

Competent regulatory authorities responsible for marine and coastal environment

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit)[22] is responsible for fundamental national environmental policy, such as conservation of groundwater, rivers, lakes and seas, waste management and recycling policy, protection, maintenance and sustainable utilization of biodiversity, etc.

The German Environment Agency (Umweltbundesamt)[23] is responsible for matters relating to emission control, soil conservation, waste management, water resources management and health-related environmental issues.

Federal Authorities for Conservation advise the Ministry of Environment. Additionally, they issue permits and support the projects in the field of environmental protection and maintenance of landscapes. They carry out scientific research focusing on environmental assessment.

State authorities (usually district or county authorities), guided by their respective state Environmental Ministry, carry out day-to-day operational activities. Their competence is usually defined geographically.

Environmental policy relevant to the issue of beach wrack

Basic Law for the Federal Republic of Germany (Grundgesetz für die Bundesrepublik Deutschland 23.05.1949) [24]

- This law lays out general principles of nature and landscape conservation, natural environment protection and management.

Waste Management Act (Kreislaufwirtschaftsgesetz 1.06.2012)[25]

- The act promotes a closed circular economy-based on recycling in order to conserve resources, reduce adverse impacts on the environment and protect natural resources.
- It aims to increase and optimise the efficient use of raw materials and to permanently remove from the environment any residual waste that can no longer be used.
- The producers or owners of waste are obliged to recycle their waste. The recycling of waste has priority over its elimination. The obligation to recycle waste is to be met as far as it is technically possible and economically acceptable, in particular if a market exists or can be created for a recovered substance or energy.

Federal Immission Control Act (Bundes-Immissionsschutzgesetz 13.05.2013)[26]

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[22] https://www.bmu.de/
[23] https://www.umweltbundesamt.de/en
[24] https://www.ecolex.org/details/legislation/basic-law-for-the-federal-republic-of-germany-lex-faoc128242/?q=fundamental+law&xcountry=Germany&xdate_min=&xdate_max=
[25] http://www.gesetze-im-internet.de/krwg/index.html
[26] https://germanlawarchive.iuscomp.org/?p=315

- The main aim of the act is to control air and noise pollution.
- This act aims to reduce potentially harmful impacts on human beings and their environment by means of risk prevention and precautionary measures.
- The act has a holistic approach to protecting all parts of the environment, including animals, plants, atmosphere, soil and water creating the legal basis upon which hazard control measures can be taken.

Water control and management under the Federal Water Resources Act (Wasserhaushaltsgesetz 3.05.2000)[27]

- The act refers to the protection and usage of surface and underground water resources as well as the development of unified parts of waters and planning water economy and flood control.

Act on Nature Conservation and Landscape Management (Bundes-Naturschutzgesetz 01.03.2010)[28]

- The act sets out the main requirements for the protection and conversation of nature, habitats and biodiversity. If an impairment of nature and landscape is unavoidable, the responsible party must compensate for the damage caused by impairment of nature and landscape. A permit is generally required for any impairment of nature and landscape.

Environmental Impact Assessment Act (Gesetz über die Umweltverträglichkeitsprüfung 1.08.1990)[29]

- The act regulates the environmental impact assessment (EIA) for activities which, in their nature, size or location, may influence the environment noticeably.
- An EIA must be carried out for large-scale projects and must cover the direct and indirect impact of the project on human beings, animals, plants and biological diversity; surface, soil, water, air, climate and landscape; cultural heritage and other material resources.

Renewable Energy Sources Act (EEG) (Gesetz für den Vorrang Erneuerbarer Energien 17.12.2020)[30]

- The act establishes priority for renewable energy sources such as offshore and onshore wind, solar PV, hydro power and biogas.
- It's three main principles are cost covering feed-in tariff, cost sharing among all customers and fed-in priorities for renewable energies.

The fertilizer regulation (Düngemittelverordnung 09.01.2009)[31]

- The regulation lays down the requirements for placing fertilizers on the market.
- Beach wrack is mentioned as a potential material for the production of fertilizer under "Components of the beach wrack from water management and beach removal" in the fertilizer ingredients section (Table 7, paragraph 7.1.6).

[27] https://germanlawarchive.iuscomp.org/?p=326
[28] https://www.bmu.de/en/law/federal-nature-conservation-act-bnatschg/
[29] https://www.ecolex.org/details/legislation/environmental-impact-assessment-act-lex-faoc088976/
[30] https://www.bmwi.de/Redaktion/EN/Downloads/renewable-energy-sources-act-eeg-2014.html
[31] https://www.gesetze-im-internet.de/d_mv_2012/D%C3%BCMV.pdf

Poland

Competent regulatory authorities responsible for marine and coastal environment

Ministry of Climate and Environment (Ministerstwo Klimatu i Środowiska)[32] supervises the activity of other authorities concerned with environment protection. It is responsible for sustainable development, preserving and sustainable use of natural resources.

Chief Inspectorate of Environmental Protection (Główny Inspektorat Ochrony Środowiska)[33] is responsible for supervising compliance with and inspecting and evaluating environmental protection provisions. It also supervises the remediation of any breach of the provisions.

General Directorate for Environmental Protection (Generalnej Dyrekcji Ochrony Środowiska)[34] main activities include implementation of environmental protection policy, NATURA2000 management, supervising investment processes and participating in issuing permits.

Environmental policy relevant to the issue of beach wrack

The Act of 27 April 2001. Environmental Law (Journal of Laws of 2017, item 519, as amended) (Ustawa z dnia 27 kwietnia 2001 r. – Prawo ochrony środowiska) [35]

- The act lays down the general principles of environmental protection in Poland, creating a framework for administration, planning and decision-making at the national level.
- Article 293 clause 5 does not directly forbid to store waste in internal sea waters or territorial sea waters introducing an increased fee for waste storage: *In case of waste disposal into inland surface and underground waters, internal sea waters or territorial sea waters an entity using the environment shall incur an increased fee amounting to 100 times the usual rate for placing the waste on a landfill.* The act, thus, does not introduce the ban from waste disposal directly (the provisions refers to any waste to sea – including beach wrack) but imposes a noticeable increase in fee.

Regulation of the Minister of the Environment of 13 April 2010 on natural habitats and species of Community interest, as well as the criteria for selection of areas eligible for recognition or designation as a Natura 2000 areas (Polish Journal of Laws of 2014, item 1713)(Obwieszczenie Ministra Środowiska z dnia 30 października 2014 r. w sprawie ogłoszenia jednolitego tekstu rozporządzenia Ministra Środowiska w sprawie siedlisk przyrodniczych oraz gatunków będących przedmiotem zainteresowania Wspólnoty, a także kryteriów wyboru obszarów kwalifikujących się do uznania lub wyznaczenia jako obszary Natura 2000)[36]

- The act specifies natural habitats that are subject to conservation. These include several coastal dunes habitats as well as the annual vegetation of the drift lines.
- Appendix 1 to the said regulation directly mentions the annual vegetation of the drift lines on the seashore as a type of natural habitat that is a matter of interest for Community. Beach wrack has been identified to be a part of this habitat. Regulation further designates

[32] https://www.gov.pl/web/klimat
[33] https://www.gios.gov.pl/pl/
[34] https://www.gdos.gov.pl/
[35] http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20010620627/U/D20010627Lj.pdf
[36] http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20140001713/O/D20141713.pdf

it as a Natura 2000 area and grants it with the code 1210. The habitat does not constitute the priority in conservation.
- The enactment allows to put a pressure over an entity to make it refrain from the removal of the annual vegetation of the drift lines for various reasons, including aesthetical or for further usage.

The Act of 13 April 2007 on preventing the damages to nature and their compensation (Polish Journal of Laws of 2014, item 1789, as amended) (Ustawa z dnia 13 kwietnia 2007 r. o zapobieganiu szkodom w środowisku i ich naprawie)[37]

- This act regulates the prevention and remedying of damage caused to the environment based on the polluter pays principle.
- It allows the Regional Directorate for Environmental Protection to impose a duty to perform corrective measures. One of such activities includes a duty to refrain from disposing the annual vegetation of the drift lines, which remains, in line with the nature 2000 programme, a habitat for protected species of plants and animals.

The Act on Waste, 14 December 2012 (Ustawa z dnia 14 grudnia 2012 r. o odpadach)[38]

- This act sets out measures for the waste management, to prevent and reduce the adverse impact resulting from the production and management of waste, limiting the overall impact and improving the efficiency of the use of natural resource, setting out liability for violation of the established requirements.
- The act does not have a direct definition of organic waste, such as beach waste (seaweeds, algae, seagrass) which could undergo recycling processes.

The Act of 13th September 1996 on maintenance of order and cleanliness within the communes (i.e. Journal of Laws of 2019, item 2010, as amended) (Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 18 października 2019 r. w sprawie ogłoszenia jednolitego tekstu ustawy o utrzymaniu czystości i porządku w gminach)[39]

- By means of article 3b the legislator has imposed over communes a duty to maintain the recycling level at a properly high level – pursuant to article 3b clause 1: Communes are committed to achieve until 31st December 2020: 1) the level of recycling and preparation for reuse of the following fractions of household waste: paper, metals, plastics and glass, at least 50% by weight; 2) the level of recycling and preparation for reuse and recovery by means of other methods with regards to construction and demolition waste, other than hazardous ones, remaining the household waste, at least 70% by weight.

The Act of 21st March 1991 on marine areas of the Republic of Poland and maritime administration (Polish Journal of Laws of 2019, item 2169, as amended) (Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 14 października 2019 r. w sprawie ogłoszenia jednolitego tekstu ustawy o obszarach morskich Rzeczypospolitej Polskiej i administracji morskiej)[40]

- The act defines the legal situation of the maritime areas of the Polish Republic, the coastal area and the authorities of the marine administration and their scope of jurisdiction.
- The maritime areas of Poland consist of the internal waters; the territorial sea; adjacent zone; the exclusive economic zone.
- Article 36 defines the coastal belt, i.e *Coastal belt includes the inland area adjacent to the seacoast line. The coastal belt includes the following: 1) technical belt – remaining the*

[37] http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20070750493/T/D20070493L.pdf
[38] https://www.ecolex.org/details/legislation/wastes-act-lex-faoc129566/
[39] http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20190002010/T/D20192010L.pdf
[40] http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20190002169/T/D20192169L.pdf

zone of mutual impacts from sea and land; this area is intended to keep the seashore in the state compliant to the requirements of safety and environmental protection; 2) protective belt – including the area in which human actions directly impact the state of the technical belt.

- Article 37a clause 2 refera to the Enactment on water zoning plan: *Zoning plans for internal sea waters, territorial sea and exclusive economic zone, hereinafter referred to as plans, shall decide on: (…) 5) the areas and conditions for: a) environmental protection and the protection of cultural heritage, b) fisheries and aquaculture, c) renewable energy acquisition, d) exploration, examination of fossil deposits as well as excavation of fossils from deposits.*

Draft of the enactment of the Minister of Maritime Economy and Inland Waterway Transport, the Minister of Investment and Development on the acceptance of zoning plans for internal sea waters, territorial sea and exclusive economic zone, scale 1:200 000.

- The enactment hasn't been passed yet.
- Appendix I includes the definitions of terms, *inter alia* regarding renewable energy acquisition – *means acquisition, processing and accumulation within sea areas energy from renewable sources, especially wind, waving, sea currents, sun and sea organisms (biogas), including erection of the structures indispensable for acquisition of energy together with accompanying infrastructure as well as structures serving for processing and accumulation of energy.*

Russian Federation

Competent regulatory authorities responsible for marine and coastal environment

The Russian Ministry of Natural Resources and Ecology (Минприроды России)[41] is the federal policymaker responsible for study, use, renewal and protection of natural resources, environmental monitoring, pollution control and waste management. The ministry co-ordinates and supervises the activities of five subordinate agencies.

Federal Service for Supervision of Natural Resource Usage (Росприроднадзор)[42] is a federal agency under the supervision of the Ministry responsible for supervision of environmental management, nature protection, waste management, and governmental ecological expertise.

Federal Agency for Water Resources (Росводресурсы)[43] is a federal agency under the supervision of the Ministry responsible for the management of water resources.

Federal Service for Hydrometeorology and Environmental Monitoring (Росгидромет)[44] is a federal agency under the supervision of the Ministry responsible for hydrometeorology, environmental monitoring, monitoring of the pollution.

Federal Agency for Fisheries (Федеральное агентство по рыболовству)[45] is a federal agency under the supervision of Ministry of Agriculture responsible for the management of fisheries and marine life in the waters of the Russian Federation, excluding internal seas, Caspian and Azov seas.

[41] https://www.mnr.gov.ru/
[42] https://rpn.gov.ru/
[43] https://voda.gov.ru/
[44] http://www.meteorf.ru/
[45] http://fish.gov.ru/

Russia has a federal legal system with environmental matters regulated at both the federal and regional level.

Environmental policy relevant to the issue of beach wrack

The Constitution of the Russian Federation of 12th December 1993 (Конституция Российской Федерации от 12.12.1993 ред. От 01.07.2020)[46]

- A basic legal act referring to the regulations on environmental protection. Article 42 underlines the right of every citizen "to live in a favorable natural environment, to be provided with credible information on its state and to receive remuneration for any damage sustained by their health and property by any infringement of ecological law.

Water Code of the Russian Federation, 03.06.2006 number 74-FZ (Водный кодекс Российской Федерации" от 03.06.2006 N 74-ФЗ)[47]

- The main law applicable to water resources management, which covers administration, management, conservation and use of surface water and ground water resources; water rights; waterworks; water supply.
- It is based upon the following principles: priority of water protection and prevention of negative environmental impact resulting from waterbodies management; conservation of protected waterbodies; purposeful use and priority of potable water supply; equal access to purchase of waterbodies; basin-related regulation of water relations; charged water management; traditional water management.

Federal Law on fishing and conservation of aquatic biological resources, 20.12.2004 number 166-FZ (as amended on 26.07.2019) (Федеральный закон о рыболовстве и сохранении водных биологических ресурсов" от 20.12.2004 N 166-ФЗ)[48]

- Law is applicable to internal sea, territorial sea, continental shelf and EEZ of the Russian Federation, fishing vessels flying the flag of the Russian Federation and navigating outside the boundaries of the Russian Federation and plots of land pertaining to the national territory used for fisheries and conservation of aquatic biological resources.
- The law regards fishing authorization and quotas, monitoring and conservation of biological aquatic diversity and its natural habitats.

Federal Act on production and consumption of waste, 24.06.1998 number N89-FZ (as amended on 26th July 2019) (Федеральный закон об отходах производства и потребления от 24.06.1998 N 89-ФЗ)[49]

- Sets basic principles and priority directions for the state policy on waste management.
- The legal framework for managing production and consumption waste in order to prevent the harmful consequences of production and consumption waste on human health and the environment as well as for the share of such waste in the business circulation as additional sources of raw materials.
- The act specifies *inter alia*: protection of human health, maintenance or restoration of favorable environment and maintenance of biological diversity. Determined directions for the state policy include maximum usage of raw materials and supplies, prevention of

[46] http://www.constitution.ru/
[47] http://www.consultant.ru/document/cons_doc_LAW_60683/
[48] http://www.consultant.ru/document/cons_doc_LAW_50799/
[49] http://www.consultant.ru/document/cons_doc_LAW_19109/

waste generation, limitation of waste generation and decreasing waste hazard class at the sources of its generation, disposal and removal of waste.

- Russian legislation divides waste into five classes, ranging from Class I (extremely hazardous) to Class V (non-hazardous). A license is required for the collection, transportation, handling, recycling or dumping of waste of Classes I to IV. Special rules are established. In particular, for municipal solid waste, motor transport, nuclear waste, medical waste, biological waste.

Code of the Russian Federation on Administrative Offenses, 30.12.2001 number 195-FZ (as amended on 02.08.2019)(Кодекс Российской Федерации об административных правонарушениях от 30.12.2001 N 195-ФЗ (ред. от 30.12.2020))[50]

- Sets the forms and extent of administrative liability for offences in various aspects of Russian law, including administrative offences related to environmental damage.
- Chapter 8 "Administrative Offenses in the Field of Environmental Protection and Nature Management", includes more than 40 articles prohibiting acts that directly cause harm to various environmental objects.

Sweden

Competent regulatory authorities responsible for marine and coastal environment

Swedish Ministry of Environment (Miljödepartementet)[51] is responsible for environmental and climate policy. The Ministry responsibilities include issues concerning biological diversity, eco cycles, marine and water environments, international environmental cooperation, etc.

Swedish Environmental Protection Agency (Naturvårdsverket)[52] is responsible for proposing and implementing environmental policies, coordinating, monitoring and evaluating efforts to meet Sweden's environmental objectives.

Swedish Agency for Marine and Water Management (Havs- Och Vattenmyndigheten)[53] is responsible for protecting, restoring and ensuring sustainable use of freshwater and sea resource including fisheries management.

County Administrative Boards of Sweden (CAB) (Länsstyrelse) are responsible for the supervision of beach protection in specific areas, mainly within nature reserves. It has a supervisory guiding function in the county, additionally reviewing all granted beach protection exemptions. Beach protection issues are handled at the CAB, mainly by the Nature Review Unit. The water unit at CAB is responsible for exemption from the dumping ban if someone wishes to dump unwanted seaweed at sea.

[50] http://www.consultant.ru/document/cons_doc_LAW_34661/
[51] https://www.government.se/government-of-sweden/ministry-of-the-environment/
[52] https://www.naturvardsverket.se/
[53] https://www.havochvatten.se/

Environmental policy relevant to the issue of beach wrack

Swedish Environmental Code (Miljöbalk 1998:808)[54]

- The code states fundamental environmental rules. The purpose of the Environmental Code is to promote sustainable development and assure a healthy and sound environment for present and future generations.
- Provisions regulating when Environmental Impact Statements (EISs) are required and what information they should contain are set out in Chapter 6 of the Code and in an underlying ordinance.
- Chapter 7 stipulates a broad variety of protection for certain areas including shoreline protection. It applies to water reservoirs, seas, lakes and rivers. All land and water areas are protected by a buffer zone extending up to 100 meters on either side from the shoreline. Local authorities may extend this zone to a maximum of 300 meters if they deem a natural protection of the seashore line insufficient.
- According to the provision of article 15: Protection of beaches is intended, in a long-term perspective, to 1) provide conditions for public access to beaches and 2) maintain good living conditions for animals and vegetation on land and in water.
- The environmental code is further elaborated and specified in the form of ordinances and regulations.

Rule on the Marine Environment (Havsmiljöförordning 2010:1341)[55]

- Pursuant to Paragraph 6, Swedish sea areas are divided into the North Sea and the Baltic Sea.
- According to Paragraph 8, Authority for marine and water environment shall remain the organ relevant for marine environment. It is responsible for the issues set forth by Paragraph 13 – providing a comprehensive picture of marine environment state, determination of costs related to the deterioration of the marine environment.
- Pursuant to Paragraph 21 the aforementioned authority is committed to developing and implementing an internal Baltic Sea environment monitoring programme.

Waste Ordinance (Avfallsförordning 2011:927)[56]

- Waste legislation is largely based on EU Waste Framework (2008/98/EC)
- Appendix 4 of the Waste ordinance contains a waste catalogue specifying different kinds of waste and producer responsibilities.

The ordinance on environmental impact assessment (Miljöprövningsförordning 2013:251)[57]

- Contains provisions stating that certain plans and programmes should be subject to environmental assessment.
- It aims to integrate environmental aspects into the plan or programme to promote sustainable development.

[54] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808

[55] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/havsmiljoforordning-20101341_sfs-2010-1341

[56] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/avfallsforordning-2011927_sfs-2011-927

[57] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/_sfs-2013-251/

European Union

The issue of beach wrack is not legally covered at EU level. There are, however, a number of directives, recommendations and strategies that could be relevant to the issue of beach wrack which touch upon the topic from different angles.

Directive is a legislative act that is binding to all EU countries in relation to objectives that must be achieved. However, it is up to the individual Member States to determine how the legal measure should be incorporated into domestic law to reach these goals.

- **Birds Directive (2009/147/EC)[58] and Habitats Directive (92/43/EEC)[59]** are frameworks for the conservation of wildlife throughout the EU. The protection of wildlife prohibits the destruction or alteration of their habitats and aims to maintain or restore a favorable conservation status to these species. **EU Natura 2000** network protects vulnerable species and habitats listed under both the Birds Directive and the Habitats Directive.
- **Water Framework Directive's (2000/60/EC)[60]** main objective of is to maintain a good status for marine waters, habitats and resources, delivering an integrated ecosystem-based approach. The WFD covers rivers, lakes, transitional waters, groundwater and coastal waters out to 1 nautical mile (12 nautical miles for chemical status, i.e. for territorial waters).
- **Marine Strategy Framework Directive (2008/56/EC)[61]** aims to protect the marine environment across Europe by achieving and maintaining Good Environmental Status of the EU marine waters. The area of application of the MSFD partially overlaps with that of the WFD, i.e. the coastal waters zone extending 12 nautical miles from the baseline. MSFD further applies in the offshore waters beyond 12 nautical miles where WFD does not reach. Among other topics MSFD addresses marine litter which is currently an overlooked part of beach wrack.
- **Maritime Spatial Planning Directive (2014/89/EU)[62]** promotes the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources. In addition, the directive promotes the coexistence of relevant activities and uses, encouraging multiple purpose uses, where it is sustainable.
- **Environmental Impact Assessment Directive (2014/52/EU)[63] and Strategic Environmental Assessment Directive (2001/42/EC)[64]** ensure that the environmental implications of decisions are taken into account before the decisions are made. EIA directive deals with individual projects, while public plans and programs are undertaken on the basis of SEA directive.
- **Bathing Water Directive (2006/7/EC)[65]** main objectives are to safeguard public health and protect the aquatic environment in coastal and inland areas from pollution.
- **Renewable Energy Directive (EU 2018/2001)[66]** establishes an overall policy for the production and promotion of energy from renewable sources in the EU, setting out precise sustainability criteria for biofuels to be considered renewable energy sources.

[58] http://data.europa.eu/eli/dir/2009/147/2019-06-26
[59] http://data.europa.eu/eli/dir/1992/43/2013-07-01
[60] http://data.europa.eu/eli/dir/2000/60/oj
[61] http://data.europa.eu/eli/dir/2008/56/oj
[62] http://data.europa.eu/eli/dir/2014/89/oj
[63] http://data.europa.eu/eli/dir/2014/52/oj
[64] http://data.europa.eu/eli/dir/2001/42/oj
[65] http://data.europa.eu/eli/dir/2006/7/2014-01-01
[66] http://data.europa.eu/eli/dir/2018/2001/oj

EU recommendation is an opinion of the EU institutions on a particular issue. Recommendations are non-binding and are of persuasive authority only.

- **Recommendations on Integrated Coastal Zone Management (2002/413/EC)**[67] promotes sustainable management of coastal zones, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics.

Further, **EU strategies** set out general direction of the policy making to achieve goals under conditions of uncertainty. Action plans outline detailed actions to achieve these goals.

- **EU Strategy for the Baltic Sea Region (COM/2009/0248)**[68] main objectives are to enable a sustainable environment, enhance the region' s prosperity, increase accessibility and attractiveness, ensure safety and security in the region.
- **Bioeconomy Strategy (introduced 2012 and updated/Action Plan 2018)**[69] promotes sustainable production of renewable resources from land, fisheries and aquaculture and their conversion into food, feed, fibre, bio-based products and bioenergy, while growing new jobs and industries.
- **EU Blue Growth Strategy (COM/2012/0494)**[70] supports sustainable growth in the marine and maritime sectors developing sectors with high potential such as aquaculture, coastal tourism, marine biotechnology, ocean energy, seabed mining.
- **EU Strategy for more Growth and Jobs in Coastal and Maritime Tourism (2014)**[71] promotes sustainable growth and competitiveness in coastal and maritime tourism. Sustainability in coastal and maritime tourism are to be strengthened by promoting strategies on waste prevention, management and marine litter, as well as Marine Spatial Planning,
- **European Green Deal (COM/2019/640)**[72] is a growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use while protecting, conserving and enhancing the EU's natural capital.
- **EU Biodiversity Strategy for 2030 (COM/2020/380)**[73] tackles the key drivers of biodiversity loss, such as unsustainable use of land and sea, overexploitation of natural resources, pollution, and invasive alien species.
- **Circular Economy Action Plan (COM/2020/98)**[74] introduces sustainability measures to transform consumption patterns so that no waste is produced in the first place.
- **Zero pollution action plan (to be adopted by the EC in 2021)**[75] intends to better prevent and remedy pollution from air, water, soil, further decouple economic growth from the increase of pollution, strengthen the links between environmental protection, sustainable development and people's well-being.

[67] https://ec.europa.eu/environment/iczm/rec_imp.htm
[68] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52009DC0248
[69] http://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none
[70] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52012DC0494
[71] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1479224038190&uri=CELEX:52014DC0086
[72] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2
[73] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380
[74] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN
[75] https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en

Regional policy

The **Baltic Marine Environment Protection Commission HELCOM** is a regional platform for environmental policy making, focusing on the protection of the marine environment of the Baltic Sea. Contracting parties of HELCOM are Denmark, Estonia, European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden.

- **Baltic Sea Action Plan (15.11.2007)**[76] is a regional plan of measures that aims to reach good environmental status of the Baltic Sea, addressing eutrophication, hazardous substances, maritime activities and biodiversity.

HELCOM has issued a number of recommendations that MS have committed to incorporating into their national laws, several of which could be relevant to address the issue of beach wrack.

- Recommendation 15/1 on **Protection of the coastal strip**[77]
- Recommendation 24/10 on **Implementation of integrated coastal management and maritime spatial planning in the Baltic sea area**[78]
- Recommendation 40/1 on **Conservation and protection of marine and coastal biotopes, habitats and biotope complexes categorized as threatened according to the HELCOM red lists**[79]

International policy

- **The United Nations 2030 Agenda for Sustainable Development (SDG)** includes 17 sustainable development goals and 169 targets. The goal of the agenda is to eradicate poverty and achieve sustainable development by 2030. The goals relate to social, ecological and economic outcomes, aiming to ***inter alia*** conserve and sustainably use the oceans, seas and marine resources for sustainable development.
- **UN Convention on Biological Diversity (CBD)** is the international legal instrument for "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources"
- **Convention on Wetlands of International Importance (the Ramsar Convention)** is an international treaty for the conservation and sustainable use of wetlands. It aims to halt the worldwide loss of wetlands and to conserve, through wise use and management, those that remain.
- **Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** aims to prevent species from becoming endangered or extinct because of international trade and to ensure that international trade of wild animals and plants does not threaten their survival.

[76] https://helcom.fi/baltic-sea-action-plan/action-plan/
[77] https://helcom.fi/wp-content/uploads/2019/06/Rec-15-1-R.pdf
[78] https://helcom.fi/media/recommendations/Rec-24-10-R.pdf
[79] https://helcom.fi/wp-content/uploads/2019/06/Rec-40-1.pdf

Case studies for innovative solutions of beach wrack use

By Chubarenko B.[1], Schubert H.[2], Woelfel J.[2]
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Introduction

This report No 5.1 is one of the main outputs of the Project CONTRA (2019–2021), which was fulfilled within the Program Interreg Baltic Sea Region. The report was prepared within the Work Package 5 "Innovative technologies for beach wrack handling and toolkit" by experts from CONTRA Project Partners. It represents the results obtained in the six case studies in the countries with different management systems: Germany (Islands of Rügen and Poel), Denmark (Køge Municipality), Russia (Curonian and Vistula spits) Sweden (Kalmar municipality and Öland) and Poland (Gulf of Gdansk).

Each case study is presented in separate chapters, which focuses are indicated in the chapter titles (see Table of contents). Technological aspects of different stages of the beach wrack collection, processing and usage (see Figure below), as well as the management and legislative issues are presented. The last chapter is devoted to Estonian experience.

The structure of chapters is generally similar. The chapters focus on different options of utilising of the beach wrack considering it as management object. The opportunities, obstacles and recommendations are highlighted based on existing practices from the case studies. As the aim of this report is to present the details and findings of the individual case studies (plus Estonian experience) a general summary was not formulated. The conclusions and recommendations were prepared as a separate document and presented by Project CONTRA partners in the Policy brief "Towards sustainable solutions for beach wrack treatment" (see www.beachwrack-contra.eu).

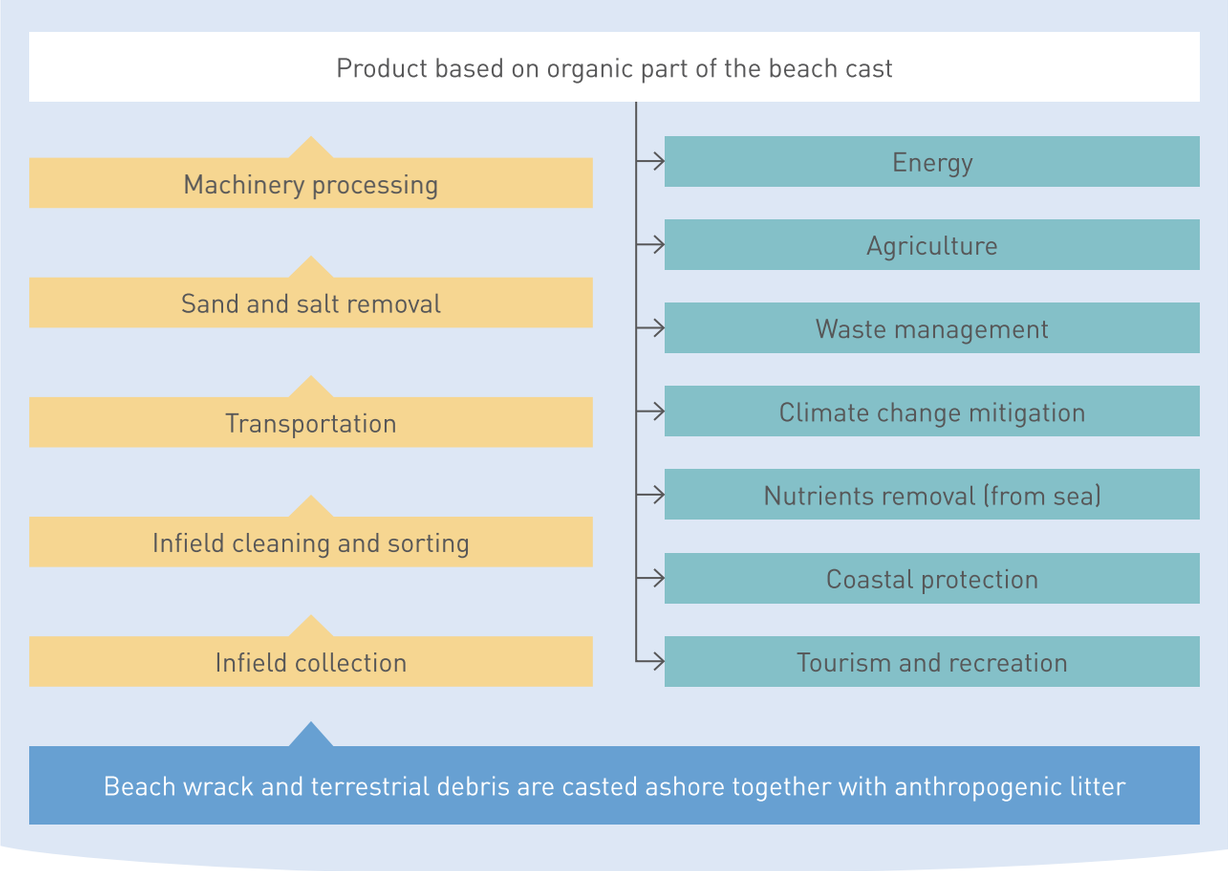


Figure. Phases of the treatment of beach wrack (organic part of a beach cast), which need management, legal and technical solutions (left. yellow), and possible uses of beach wrack born products in different sectors and applications (right, green) [Chubarenko et al., 2021].
Legend: Natural effect | Actions that need better solutions | Products | Usage/Benefit

Case study 1: Beach wrack-based soil production (Wrack4Soil)



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Case study partner: Hanseatische Umwelt CAM GmbH

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

Aim of the case study: to improve the process chain of beach wrack for soil production from the technical & management perspective. Development and implementation of new business concepts for beach wrack-based soil 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 have been tested, and collaboration with municipalities has been deepened.

Staff involved: Martin Staemmler, Steffen Aldag, Sebastian Staemmler, André Buchwald

1.1 Location and geographical description

The case study region covers the coastline from Travemünde to the Peninsula Darß/Zingst in the federal state of Mecklenburg Western Pomeranian (→ Fig. 1.1). This coastal section is part of the Mecklenburg Bay in the Western Baltic Sea. The composting plant is located in Sandhagen, between the two Hansa Cities Rostock and Wismar. The distance to the coastline is about 15 km.

The Hanseatische Umwelt processes up to 10,000 m³ of compost and various soils per year. In addition to the production of marine biomass compost/soil, the company advises farmers and local authorities, offers services in horticultural landscaping, and is involved in research and innovation projects about marine biomass recycling.

1.2 The effect of beach wrack in the case study area

The Hanseatische Umwelt is processing beach wrack from four beach spots (in four municipalities) within a radius of approx. 50 km to the composting plant Sandhagen (→ Fig. 1.1). The qualitative composition of beach wrack from one beach section varies depending on the season, the collection technique, the duration and type of storage in respective facilities. Every beach spot has its own "typical" dominating plant species in the organic beach wrack composition. In the "catchment" area of 50 km around the composting plant, the common sea grass (eelgrass) *Zostera marina* dominates the beach wrack mixtures. The sand content is an essential parameter for the beach wrack material's machinability and is highly impacted by the beach cleaning procedure and material loading with heavy machinery. The sand content of freshly installed beach wrack piles varies between 50–95 %. The long-term storage of beach wrack in interim storage facilities leads to degradation processes of the organic fraction. It thus hinders further processing, especially the separation of the organic fraction from mineral components.



Figure 1.1 Beach wrack raw material supply of Hanseatische Umwelt (PP14) in the region of Bad Doberan, Germany



Figure 1.2 Temporary beach wrack pile on tourist beach (Island of Rügen, Binz, Germany, July 2014)

One of the four municipalities, the Island of Poel, is cleaning the beaches by itself. Other three municipalities have contracted a service supplier cleaning their beaches, e.g. Rerik, Kühlungsborn and Warnemünde (Rostock).

One of the main suppliers of beach wrack in the case study was the municipality of the Island of Poel. During one season beach wrack material from the Island of Poel needed to be sieved one or two times, and the organic parts were transported to the Sandhagen composting plant. The Island of Poel has a coastline of about 11 km with sandy beaches, while 3 km of them are managed and cleaned regularly in the high season (7 months; from April to October). The overall quantity of beach wrack collected in the managed area varies between 3,500 and 4,500 ton/year, resulting in 166–214 tons per month per km.

1.3 Why is the beach wrack a nuisance in the case study area?

The managed beaches in the region of the case study "Wrack4Soil" are regularly cleaned for touristic purposes. Often, significant amounts of collected beach wrack are stored in temporary piles on or near the beach (→ Fig.1.2). If the temporarily stored material is not processed quickly or stored correctly, leaking leachates and climate-relevant gases (methane, nitrous oxide) can harm the environment. Also, intensive biological decomposition means that organic and mineral components are more difficult to separate by machines.

Looking into an economically valuable processing chain of beach wrack, it has to be considered that the resource beach wrack is only available from managed beach areas. However, the major part of the beaches in the region of "Mecklenburg Bay" between Travemünde in the west and the Darß peninsula in

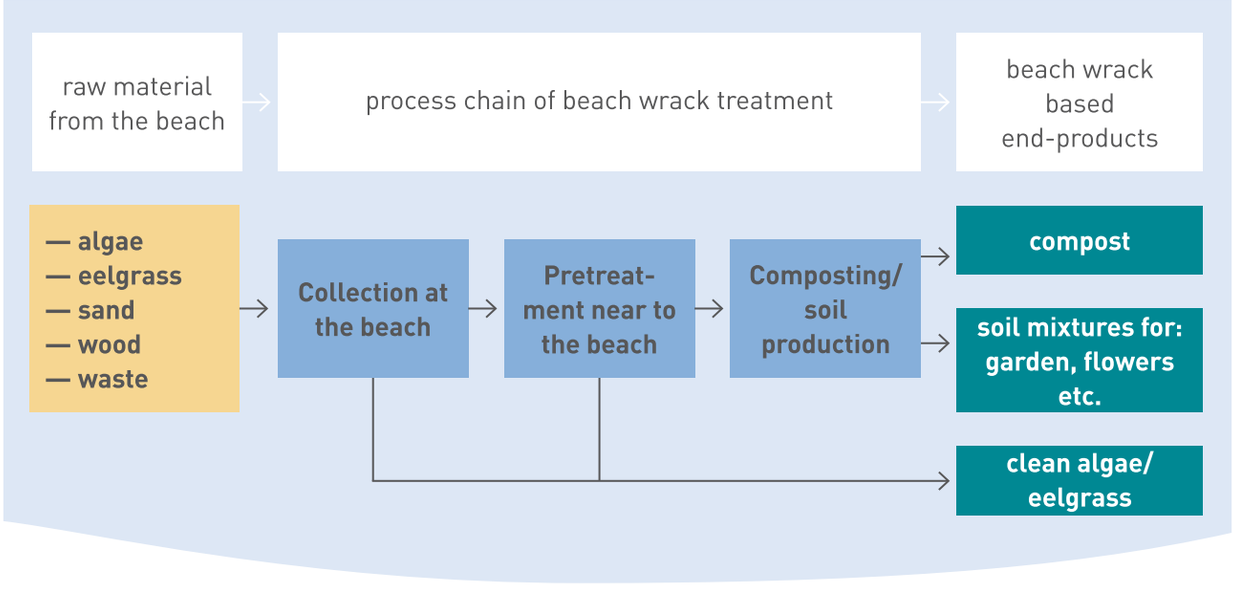


Figure 1.3 Exemplary recycling chain of beach wrack for the production of beach wrack-based soil products and higher-value recycling pathways



Figure 1.4 Collection with a tractor and a beach cleaning vehicle "Beach Tech STR 2000" (Island of Poel, Germany, July 2020)



Figure 1.5 Beach wrack collection in the splash zone using a tractor with a pitchfork and a rake (Island of Poel, Germany, July 2020)

the east are not managed (natural beaches). These beaches are never cleaned from beach wrack material and are partly protected by environmental law.

1.4 Technology and methods of collection and composting

To improve the recycling and supply chain of beach wrack, different recycling pathways in the field of soil improvement products were tested and further developed. The knowledge of co-composting of beach wrack as one of the most promising recycling solutions for the treatment of large quantities of beach wrack was investigated in more detail. Additionally, higher-value recycling pathways for using separated raw materials of beach wrack, such as eelgrass or macroalgae, were part of the case study. For example, washed pure eelgrass can be used as filling material for pillows and mattresses, and clean macroalgae can be used in pharmaceuticals. The main recycling routes of beach wrack considered in this study are shown in → Fig. 1.3.

1.4.1 Raw material supply from the beach site

Beach wrack has to be collected from the beach or the drift line when it is available. Environmental conditions strongly influence the availability, quality and quantity of beach wrack. Thus, the collection method needs to be adapted to the planned recycling options, like composting or processing a single raw material. On the other hand, the beach operator's requirements (e.g. the municipality) must also be taken into account, when recycling the material collected on the beach.

1.4.2 Example of beach cleaning methodology (Municipality of Poel, Germany)

The municipality of Poel is cleaning the beaches with a combination of two different collection methodologies. These methods were studied focusing on the recycling chain's optimisation: how does the collection/cleaning method impact the chosen recycling pathway?

Beach wrack and waste collection in sandy beach areas

To regularly clean the sandy areas above the drift line, a beach cleaning vehicle "Beach Tech STR 2000" is used. This technology is preferably applied to clean the beaches by sieving the fine sand and separation of waste, like crown corks and cigarette buds, rather than collecting fresh beach wrack (→ Fig. 1.4). However, small amounts of dry beach wrack can be collected with this machine.

Beach wrack collection in the drift line

The major part of the beach wrack accumulated in or slightly above the drift line is pushed together by a tractor with a front loader and a pitchfork and a fixed rake in the back of the tractor (→ Fig. 1.5). The tractor's front loader loads the collected material to a truck with a tipping platform or a tractor with a dump trailer for further transportation. The collected material is stored in temporary piles on the beach. Afterwards, the collected beach wrack material is transported to the Poel municipality building yard for storage and further processing (dewatering, screening).

Collection of fresh and clean eelgrass with a stone fork and plastic bags (tested by Hanseatische Umwelt CAM GmbH in June/July 2020)

Experiences with the direct removal of eelgrass with heavy equipment (a tractor with a front loader and a pitchfork) have shown that a lot of dirt, decomposing macroalgae and sand were taken up. Therefore, it is necessary to manually collect the



Figure 1.6 A big-bag trolley for transportation of eelgrass manually collected with a stone fork (Island of Poel, Germany, July 2020)



Figure 1.7 Screening of the beach wrack at the temporary storage facility at Boltenhagen, Germany, July 2020

fresh disposed material in the the shallow waters of the drift line with a stone fork to get clean and sand-free eelgrass. Although this collection method cannot be considered an effective beach cleaning activity, the manually collected material still reduces the total amount of beach wrack that the municipality has to remove from the beach. The collection of eelgrass should be performed as soon as the material is washed up (e.g. after storm events) early in the morning or late at night before the municipality starts the regular cleaning. The eelgrass is collected and transported in 1 m³ plastic "big bags" for further storage and processing. The big bags can be moved by tractor with a front loader or a small excavator. In case when the heavy machinery is not available or prohibited on the beach, a beach suitable big-bag trolley (up to 300 kg of fresh and wet eelgrass) can be used (→ Fig. 1.6)

As an alternative semi-machinery approach, the eelgrass can be manually pre-collected by a stone fork to get several small piles. The piles are then loaded with an excavator on heavy beach-suitable transport means/vehicles (a truck or a tractor). The manual pre-collection of eelgrass helps to reduce the share of algae, sand and other impurities in the eelgrass. This collection method might also supplement the regular mechanical cleaning by the municipality.

Beach wrack used for composting purposes

Baltic beach wrack collected at the Island of Poel between winter and autumn 2019 and 2020 was used as co-composting material in the case study. Currently, the material is collected by the building yard of the municipality of the Island of Poel. Only managed beach areas are cleaned regularly in the period between April and October. The Hanseatische Umwelt is regularly contracted to screen beach wrack and transport the organic part to the composting plant. In the first treatment phase near the beach, the beach wrack material is usually screened with 20 or 30 mm mesh size in a drum screening plant (→ Fig. 1.7).

1.4.3 Processing and storage of biomass at the composting plant site

The oversize particles (organic) from screening activities near the beach with less sand are transported to be used as, e.g. co-composting material at the plant. The sand fraction with less or only small organic particles is transported back to the beach for coastal protection. Experiences showed that the longer (approx. >2–3 months) the storage time of beach wrack is, the more difficult the separation of sand and organic material becomes afterwards. The continuous decomposition in a pile causes eelgrass to break into smaller pieces and remain in the sand fraction during the screening. This leads to a high organic matter content in the sand, making it more challenging to return the sand to the beach due to its darker colour and regulatory requirements. In conclusion, for the municipality and the beach wrack recycler, quick processing with separation of sand and organic matter would be advantageous.

1.4.4 Washing and drying of undamaged clean and long fibrous eelgrass

The washing procedure of collected pure eelgrass (raw material) is essential to establish a recycling chain for higher value application, like house insulation or filling material for pillows and mattresses. The sand, mud, small algae parts and mussels, other marine debris and the salt stuck to the surface of the eelgrass leaves are washed away using freshwater (rain or tap water). This leads to less



Figure: 1.8 Building of the eelgrass washing unit at the Hanseatische Umwelt CAM GmbH facilities, June 2020)



Figure 1.9 First operation of the washing unit at the Hanseatische Umwelt CAM GmbH facilities, July 2020)



Figure 1.10 Active drying with a fan and an electrical heater in wooden drying boxes at the Hanseatische Umwelt CAM GmbH facilities, July 2020)



Figure 1.11 Passive (pre-) drying on a wooden structure at the Hanseatische Umwelt CAM GmbH facilities, July 2020)

hygroscopic material. After the washing process the intensive smell of the eelgrass transfomes to a slight pleasant smell "of the sea".
It is recommended to use rainwater for making the eelgrass washing environmentally friendly.
Another washing and drying method to clean pure eelgrass is to spread the freshly collected material on green areas to get it washed by rain and dried by the sun and wind. This traditional treatment method was commonly used in the first half of the 20th century in Europe and North America (Wyllie-Echeverria & Alan Cox 1999). Danish farmers still use it.

Installation of a 3-chamber washing system with wastewater treatment

A prototype of a 3-chamber eelgrass and algae washing system was installed at the facilities of the company. The system consists of three open intermediate storage containers (chambers) and a water treatment loop to filter the suspended matter and reduce the nutritional load (→ Fig. 1.8, 1.9). Rainwater is used to wash the mix of beach wrack and sand. Preliminary small-scale washing experiments were conducted. Results showed that fresh eelgrass should be washed at least three times to remove any dirt, algae and sand. Consequently, a 3-chamber system was designed and installed.
After moving the net bag from one chamber to another, the washed eelgrass was pulled out of the chamber to drain the water off. In the prototype, the net bags were moved with an excavator. It seems reasonable to install a kind of beam above the chambers with a sliding pulley system installed on a track, which makes the washing unit more independent from heavy machinery.

Experiences of using the washing unit to wash manually collected eelgrass

Fresh and relatively clean eelgrass was collected using stone forks at the managed beach site "Schwarzer Busch" on the Island of Poel on the 7th of July 2020. Two big plastic bags with totally 293 kg of fresh and wet eelgrass (FW) were collected, resulting in 27 kg of dry weight (DW) of clean material plus 2.5 kg DW of mussels, algae, sand and stones (FW/DW ratio of about 1:10). After the eelgrass was



Figure 1.12 (a) raw eelgrass, (b) shredded eelgrass, (c) eelgrass pellets, (d) eelgrass pellets with added water

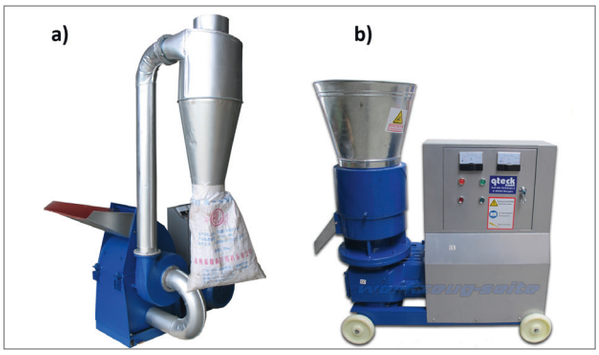


Figure 1.13 (a) Hammer Mill HM 426, (b) pelleting machine PP295UG-S (picture source: https://www.qteck.de/)

washed in the three washing chambers, the drying process, with passive pre-drying on a wooden structure (→ Fig. 1.11) and active drying at the facilities of Hanseatische Umwelt started (→ Fig. 1.10). After seven days, the eelgrass was dry and ready to sell. Before loading the dried material into plastic bags, we had to separate some sand from the eelgrass's roots.

Use of the existing algae and eelgrass drying facilities of Hanseatische Umwelt

The freshly washed eelgrass needs to be dried quickly. The Hanseatische Umwelt has an algae/eelgrass drying room with electrical pre-heated circulating air. The drying facilities are designed for small to medium quantities. Experiences with the drying of fresh washed wet eelgrass have shown, that only a small layer of approx. 5–10 cm of washed material can be placed in the drying boxes (→ Fig. 1.10), and the material needed to be turned up to 2 times a day. The experience with the applied drying method has also shown that it makes sense to pre-dry the eelgrass in the air. For this purpose, we have built a wooden structure, on which the eelgrass can be placed for pre-drying (→ Fig. 1.11).



Figure 1.14 Compost piles with wireless temperature probes at the Hanseatische Umwelt facilities, October 2019

1.4.5 Test of shredding techniques to cut beach wrack components

Dried eelgrass collected with heavy machinery in July 2020 at beaches of the Island of Poel was used to test eelgrass/beach wrack shredding with subsequent pelleting. The eelgrass was not washed but only dried. The material was slightly mixed with sand and algae. A 6-mm screening matrix was used to shred the material before pelleting. Longer fibres of eelgrass were produced by using the 8-mm matrix. The longer eelgrass fibres (15–25 mm fibre length) can be used as a primary material for producing acoustic or insulation boards for building construction. The shredding and pelleting trials were conducted by the manufacturer of the hammer mill and pelleting machine[1]. The machine model No. PP295UG-S with 15 KW electrical power was applied for pelleting (→ Fig. 1.13). These pellets can be used as an organic fertiliser product for regular and balcony gardening (→ Fig. 1.12).

1.4.6 Composting of beach wrack

Preparation of the raw material for composting

The green waste material was shredded with a slow-speed shredding machine (Komptech "CRAMBO 5200 ec direct") with 180-mm mash size before preparing the compost piles. The shredded material was then mixed with 10 % of loamy soil to get a mineral component, needed for the composting process. Clay particles with their large surface improve the biological colonisation of the compost.

1 Manufacturer of hammer mill and pelleting machine: https://www.qteck.de/index.php/maschinen-werkzeuge/energie-und-futtertechnik

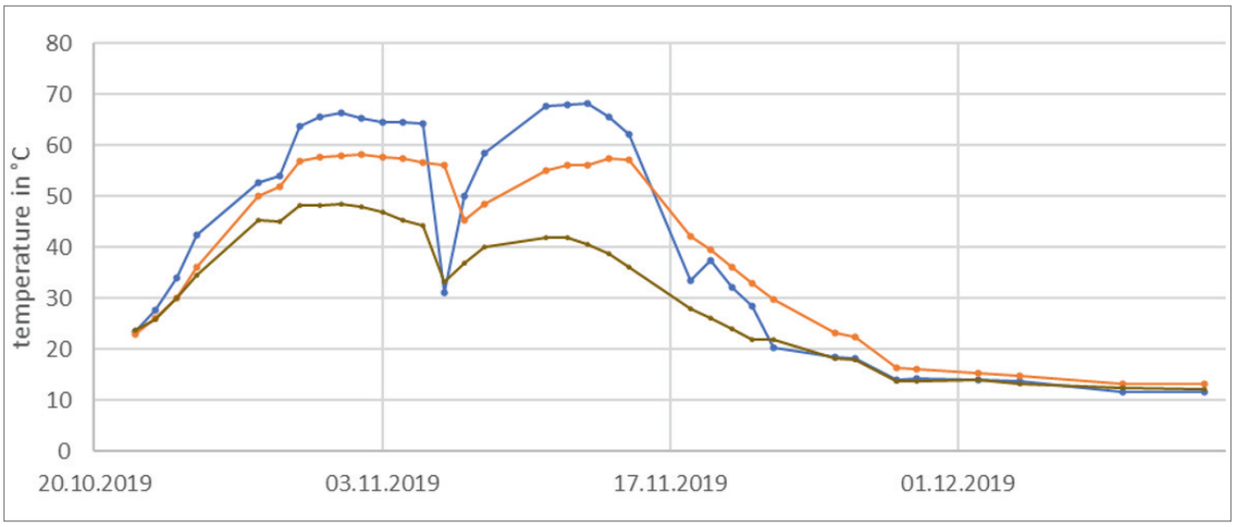


Figure 1.15 Temperature development of decomposition processes in the respective compost piles (100 % green waste (blue line), and the respective beach wrack proportions: 30 % – red line, 50 % – brown line) tested at the Hanseatische Umwelt composting facilities in 2019

Setting up the compost piles

Before the final material mix was put in place, the green waste and the beach wrack were premixed in a cone. A pile with 50 % of beach wrack-share, one with 30 % of beach wrack-share and a pile with 100 % of green waste without added beach wrack have been placed into the compost boxes and covered with a green breathable compost fleece. The material was moved with a small excavator having a 0.5 m^3 shovel.

Temperature and CO_2 monitoring

During the composting process, the temperature was monitored continuously using wireless temperature probes (→ Fig. 1.14). The CO_2 content of the compost piles was measured by using a semi-quantitative measurement system. The released CO_2 was pumped through a lance into the measuring cylinder filled with potassium hydroxide solution (KOH). The solution expanded on contact with CO_2 and indicated the volumetric % of CO_2 in the compost gases. Both measurements of temperature and CO_2 (vol. %) indicate the status of the rotting process. The presence of sufficient oxygen and the right ratio of carbon to nitrogen in the biomass of 35/1 leads to an optimal decomposition of organic matter by microorganisms and fungi. Furthermore, the compost should be moist enough for optimal microbial degradation.The decrease of CO_2 and temperature in the core of the compost pile indicates a reduced aerobic microbiological activity of the compost process. In this case, the compost pile is usually turned to bring fresh and nutrient-rich material and oxygen into the core of the compost.

Regular turning of the compost piles

By turning the compost pile, material that has not yet decomposed is re-mixed into the pile from the outside. The rotting process continues, whereby the temperature also rises again. The moving aims to mix the material and supply the compost pile with oxygen.

The sudden minimum in the middle of the diagram shows a turning event of the compost piles (→ Fig. 1.15). After turning the piles, the temperature drops down immediately. However, the temperature rises again rapidly, if the raw material still has enough microbiologically usable energy.

Comparison of temperature development in green waste and beach wrack compost piles

With increasing the share of beach wrack in total biomass (in relation to green waste), the temperature decreased during the decomposition process (→ Fig 1.20). The brown line of 50 % green waste demonstrated this trend, while the temperature didn't exceed the threshold value of 50 °C.

According to the German Regulation on the recycling of biowaste from agriculture, forestry and horticulture (BioWaste Regulation – BioAbfV) the compost material must be disinfected according to the following criteria: "During the aerobic disinfection treatment the temperature of at least 55 °C must be applied continuously to all rotting material for at least two weeks, or 60 °C for six days, or 65 °C for three days. Due to moving the compost pile from time to time, the plotted temperature shows its minimum in the first interval.



Figure: 1.16 Shredding and mixing of green waste and beach wrack



Figure 1.17 Adding additives to the compost

1.4.7 Additional fields of beach wrack application – eelgrass as mulch material

Usually, the strawberry farmers place straw under the adult plants to protect the fruit from humidity and any diseases of fungal infections. Inspired by private gardeners' reporting about several positive effects on fruit development, we tried to use eelgrass for a couple of strawberries plants in the open field on their size and taste. We assume that apart from protecting the fruit from humidity and direct contact to the soil, the eelgrass can positively affect the plant and the fruit growth. The eelgrass covers the soil surface around the plant, keeps the soil warm and reduces the water vaporisation. It is also known that several acids (rosemary and zosteric ones) on the eelgrass leaves' surface protect the eelgrass from biological degradation having an anti-fouling effect [Papazian et al. 2019] that might also protect the plant and the fruit from diseases or fungal infections.

1.4.8 Development of new beach wrack-based soil products at the Hanseatische Umwelt CAM GmbH

In May 2020, a new composting trial with an 18-m³ compost pile was launched. Very fresh green waste was mixed with 8 m³ of fresh beach wrack, that resulted in an approx. share of 30 % beach wrack to 70 % green waste (→ Fig 1.16). Biochar and other mineral additives were added during the composting process (→ Fig. 1.17).

1.5 Management-based obstacles

The Hanseatische Umwelt tried to establish a reliable supply chain with beach wrack material to build up a continuous production of beach wrack products.

One idea was to establish a long-term supply and purchase beach wrack contracts based on an estimated annual average of biomass. A draft contract was presented to the Poel Island Municipality, the associated partner of CONTRA (AP13). Such a long-term contract is difficult to implement for the municipality due to an annually renegotiated budget. On the other hand, other municipalities in the case study area consider a long-term contracting of beach wrack cleaning and recycling services. But the common practice of the municipalities is still to tender for beach cleaning and beach wrack recycling. Due to these uncertainties, the supply of a certain/expected minimum amount of beach wrack biomass cannot be guaranteed over the years. These unsatisfactory conditions make it difficult to develop products, build up processing infrastructure and establish a sustainable, economically viable marketing concept.

1.5.1 Administrative / legal obstacles

The use of compost in agriculture is limited due to the national and EU fertiliser legislation. Knowledge about positive impacts of compost application to agricultural land and its ecosystem services (reducing nutrient leaching, storage of water, long-term carbon storage, etc.) needs to be disseminated to farmers, politicians, and water supply associations.

Besides, the advantages of using beach wrack or beach wrack-based substrates as organic fertiliser and soil conditioner in coastal agricultural zones need to be identified and considered in the fertiliser legislative framework. Using this organic fertiliser could reduce the application of mineral fertiliser in the Baltic coastal region and thus reduce the nutrient input into the Baltic Sea.

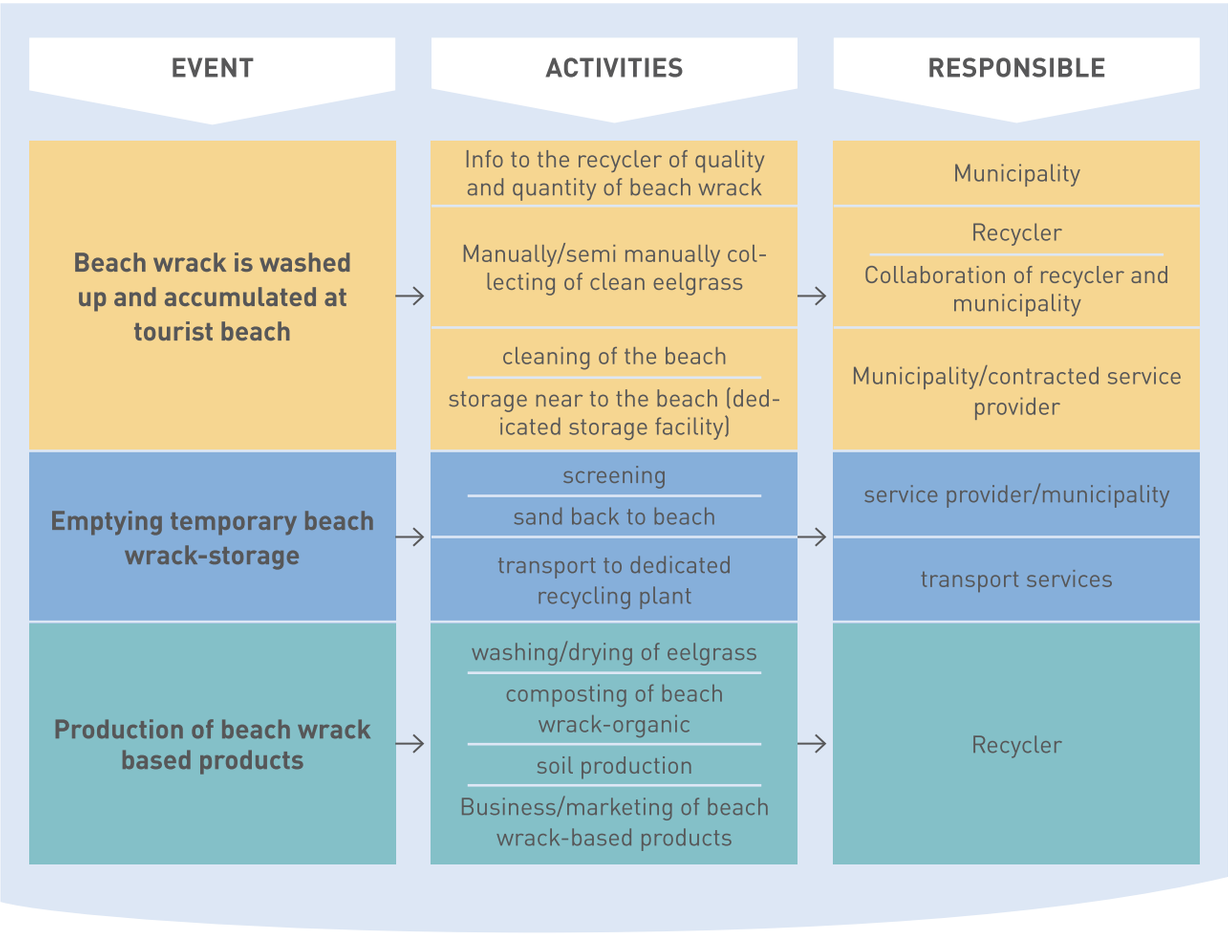


Figure 1.18 Desirable organisation scheme of beach wrack recycling chain in the "Wrack4Soil" case study area

1.5.2 Proposals for potential solutions

One of the significant challenges of building up an economically feasible beach wrack recycling chain is good communication with the municipality, as a raw beach wrack-material supplier. The way of cleaning the beaches (technical method) and the time of response between the appearance of beach wrack and the cleaning activities start significantly influence the quality of beach wrack. Therefore, directly after the occurrence of beach wrack, a process of communication between the municipality and the recycler in charge must be initiated. This is especially important when the recycler aims to get high-quality eelgrass/algae before the municipality starts cleaning activities.

→ Figure 1.18 shows a desirable event-based communication flow chart. The chart is not only showing the event and the necessary activities, but also a responsible party. Regarding the quality of screened material, it would be much appreciated to conduct the screening of the material directly after the beach's collection. This will increase the material quality and reduce the temporary stored material's biological degradation with its negative environmental effect resulting from leachate and methane emissions.

1.6 Conclusions

Different recycling pathways of beach wrack to produce soil products were tested during the case study "Wrack4Soil". One of the significant challenges in practical implementation is establishing recycling processes that are tailored to the availability and quality of the raw material with municipalities playing the role of beach wrack-suppliers. To further develop recycling methods for beach wrack, it should always be considered that material can only be provided from managed beaches. Thus, it is important to know the municipalities' requirements and build up a close partnership with them.

Different recycling pathways, as well as processing methods, were tested. The focus was on the co-composting of beach wrack as one of the most promising recycling solutions for significant amounts of mixed beach wrack material. In addition

to studying the recycling chain and processing methods, various applications of beach wrack in the processed or raw form were investigated.

1.6.1 Potential solutions

Composting

The recommended recycling method of mixed and dirty material (wood, plastics, plants, sand, etc.) is the co-composting of beach wrack with terrestrial green waste. Therefore, the presented case study had its focus on the co-composting of beach wrack. The industrial thermophile composting method lead to fast remineralisation of a large amount of heterogeneous organic material. During this process, pathogenic bacteria and germinable seeds and several organic pollutants are eliminated by the compost's microbiological colonisation. Researchers recently reported a high degradation rate of microplastics in hyperthermophilic composting [Chen et al., 2019].

The advantages and disadvantages of beach wrack composting are as follows:

Pros:

- large quantities of beach wrack are processed;
- sand content is favourable for soil structure (≤ 30 %) because sand particles aerate the soil and provide mineral content while composting;
- disinfection of biomass by high decomposition temperatures;
- degradation of possibly existing organic pollutants;
- long-term carbon sequestration;
- established and approved process and documentation procedure, especially concerning pollutants and other components.

Cons:

- time-consuming and labour intensive;
- licensed recycling company required;
- mechanical effort (moving, screening, transportation);
- monitoring and documentation obligations.

Processing of raw and separated eelgrass

The case study was also intended to address harvesting and processing the long-leave eelgrass material, which can be used for mattress and pillow fillings. Practical tests on the beach and at the composting plant confirmed that purely mechanical collection as part of regular beach cleaning does not produce high-quality material. Subsequent processing of heavily contaminated material (sieving, washing, etc.) is very labour and energy-intensive. Therefore, if a recycling chain for high quality and high-priced eelgrass needs to be established, it is necessary to harvest the material independently of the regular beach cleaning. Once the material is contaminated with sand, algae and litter by the use of heavy equipment, it can usually no longer be used for higher-value applications. Still, it can be used as mulch material in gardening or directly in composting.

With regard to the economic exploitation of high-quality eelgrass, the greatest challenge is still the fluctuation in quality and quantity. Furthermore, there is a seasonal concentration of eelgrass accumulations in late summer and autumn. This means that personnel and equipment must be ready to work as soon as the eelgrass is washed up. Here it becomes clear that a business model that exclusively focuses on the harvesting of eelgrass cannot work economically. Instead, combining other business areas, such as washing and processing agricultural products (e.g. herbs, salads) should be considered. Investments in professional sorting, washing and drying equipment can only be made if the machines and personnel are fully utilised throughout the year.

The main findings of the collection and processing trials of eelgrass carried out are as follows:

- Collection of eelgrass independent from regular beach cleaning is necessary.
- Eelgrass collected by heavy machinery cannot be used for high-value applications anymore.
- A combination of manual (a stone fork) and mechanical (a tractor, a front loader) work is possible, and synchronisation of "cleaning" and "harvesting" is crucial.
- Eelgrass collection needs to be integrated into the overall beach management of the municipalities.
- Eelgrass processing needs to be combined with other agricultural business sectors (herbs/salads production) for economic success.

Development and production of new soil mixture with beach wrack-based compost

High quality and mature compost is a valuable soil conditioner and organic fertiliser and the basis for the production of commercial cultivation substrates (soil mixtures) for various applications, like lawn areas and private gardening. Many of the soil mixtures produced at the Sandhagen Composting plant already contain beach wrack-based compost. To increase marine biomass recycling's added value, we developed a new beach wrack-based soil

mixture for particular use in private regular and balcony gardening.
Selling high-quality soil products, at a higher price per kg, will increase the added value. On the other hand, it will make it possible to reduce the cost burden of the municipalities for beach cleaning and recycling of beach wrack.
The idea of producing new beach wrack-based soil mixtures was to emphasise the unique selling proposition of beach wrack with its known effects on plant growth and health and rediscover the knowledge of traditional use of beach wrack in agriculture.
The other important marketing aspect is the sustainability of the product. It is produced based on local raw materials without the addition of peat. The use of environmentally friendly and plastic-reduced packaging illustrates the claim to produce a sustainable and holistically designed product. The most essential identified product properties are:

- an added value of beach wrack;
- locally and sustainably produced high-quality soil without peat, as a marketing concept;
- rediscovering the knowledge of traditional use of beach wrack in agriculture and gardening.

1.6.2 Findings of the case study

Achieved improvement

- Improvement of the partnership with municipalities;
- The first step to establish the continuous raw material supply of beach wrack;
- Development of marketing concepts/product labels for existing beach wrack-based products of the Hanseatische Umwelt (beach wrack-based compost);
- Development of new soil products with beach wrack as a unique selling proposition;
- Increased added value through product development;
- Increasing awareness about the advantages of compost use.

Technical issues

- Co-composting with 30 % of beach wrack (and 70 % green waste) seems to be optimal.
- Long-term storage reduces beach wrack quality due to nutrient loss and degradation processes (methane, leachate).
- Quick screening of beach wrack after collection could be beneficial for the recycler and municipality.
- Sand share of up to 30 % of the weight is tolerable for composting.
- Collecting raw, clean eelgrass from beaches needs manual work and/or a combination of manual and mechanical work.

Legal issues and identified obstacles

- Establishment of continuous material supply is difficult.
- Close cooperation of the recycling company and the municipality is crucial.
- Tendering for beach wrack recycling services makes it difficult to plan production (a still common practice).
- Long-term contracts with municipalities need to be negotiated.

Case- and site-specific challenges

- Continuous raw material supply is crucial for scaling up the production.
- Risk of being dependent on beach wrack supply for product manufacture is still high.
- Treatment of eelgrass needs to be combined with other agricultural business sectors (herbs/salads production).

Case study 2: Bio-coal from beach wrack (BWC)



Authors: Garrels T.

Case study partner: KS-VTCtech GmbH

Location of the case study: Island of Rügen, Germany

Aim of the case study: to prove the concept of producing biochar from beach wrack, to determine the properties of biochar made from beach wrack, and to assess the economic feasibility of a treatment plant.

Test/research done: Carbonization tests, laboratory analysis of biomass and biochar.

Staff involved: Timo Garrels, Klaus Serfass, Bernd Rogge

2.1 Location description and the tourist situation

The Island of Rügen (→ Fig. 2.1) is the largest and most populated island of Germany. It is located on the northern shoreline of Mecklenburg Western Pomerania, and can be reached by bridge from the city of Stralsund. With 77,000 permanent inhabitants and around 7.2 million overnight guests (2019) [Graefe, 2020], it is the most important touristic location in the German Baltic Sea region.

The main touristic hotspots are located on the eastern shoreline, ranging from Kap Arkona (the northern tip of Rügen) over Breege / Juliusruh with the largest beach on the island, Glowe, Lohme, Sassnitz, Binz, Baabe, Sellin, Göhren to Thießow (the south-eastern tip of the island).

Since the island's eastern shoreline is also the area with the highest emergence of beach wrack (→ Fig. 2.1), which is seen as a nuisance by the majority of tourists, local communities and tourism administrations struggle with beach cleaning and beach wrack disposal during the tourist season, which is mainly from May to September.

The western and southern shoreline of the island does not suffer from large beach wrack quantities. Since the area is not of much touristic importance, there is little demand for collection and disposal of beach wrack in that area.

The actual growth of beach wrack, a mixture of seagrass, seaweed and various algae, along with other debris, mainly happens at higher water temperatures in summer. However, in the context of this study, it's not the growth time that is relevant, but the time of the release of the material on the beach. Depending on the wind direction and weather conditions, this happens more or less throughout the year, but the beaches are only cleared during the tourist season.

2.2 Assessment of the beach wrack yield

Both Associated Partners of case study (CS) 2, the municipality of Sellin (AP14), and the municipality of Breege/Juliusruh (AP15) (→ Fig 2.1) perform beach management activities during the season of May – September, but could not provide reliable data on the exact amount of beach wrack they had collected and disposed of during the term of the project.

On the one hand, they do not weigh beach wrack during collection or transportation from the beach; on the other hand, they usually do not dispose of the material on the per ton cost basis, therefore, they do not need the recording of mass data.



Figure 2.1 Island of Rügen, Germany – the main area of beach wrack emergence

The municipality of Sellin (AP14) has a beach length of roughly 1.6 km and removes the beach wrack daily during the beach management season. Some sand is separated on-site, and then the collected material is transported to a municipal composting facility. The collected beach wrack mass can be estimated at roughly 200 t/a, including an unknown amount of remaining water and sand.

The municipality of Breege/Juliusruh (AP15) has a total beach length of 8.5 km, of which around 1.5 km are being managed during the season. Beach cleaning is done on demand, and the picked-up material is usually stored on an unmanaged part of the beach.

The total beach wrack emergence in the area of Rügen is impossible to quantify since there is no official data available. Our estimations come to roughly 30 thousand m³ per year, of which less than 50 % is collected and disposed of during the beach cleaning season. Since the picked-up material can contain large weight fractions of water and sand from the beach, beach wrack organic dry matter can only be roughly estimated at around 1–2 thousand t per year.

Beach cleaning options and obstacles

Beach wrack is a collective term for all kinds of marine plants, algae, wood, debris, waste, animal carcasses, etc. Therefore, depending on the regarded area and season, there can be considerable differences in the appearance of beach wrack within the case study area.

On the island of Rügen, beach wrack material varies from coarse and fibrous materials like fresh seagrass to fine algae materials that appear to be almost liquid. During the case study, we could not identify any dependency on a particular season or location.

The beaches on the island of Rügen are only cleaned during the tourist season. The tourists, who visit the island mainly for a beach holiday, expect well-tended beaches from the tourism administrations. Not to hinder tourism, which is the main source of income on the island, beach cleaning usually occurs in the evening and early morning hours.

2.2.1 Common beach cleaning machines

To this day, machines used to clean the beaches are the ones commonly used in construction and agriculture: wheel loaders, excavators, and tractors with trailers for removing the material. These machines are robust and durable, but not specifically designed for the beach cleaning purpose.

As a result, the cleaning performance is very different depending on the material to be removed, and the cleaning quality is limited. A significant amount of beach wrack remains on the ground, or a large amount of sand is removed along with the biomass. To remove beach wrack from large beach sections in a short time, specially designed machines would be required. The already mentioned considerable differences in the appearance and structure of beach wrack in the region further complicate a fast and thorough cleaning of the beaches, because the different machines deliver different cleaning results for the respective material structures.

In general, using agricultural machines for beach cleaning appears to be a good idea, since beach cleaning is only carried out during the summer months. Therefore, the equipment used by the municipalities can also be used for winter services (snow removal, a sprinkling of salt on frozen roads, etc.) and maintenance of public green areas.

In the case study area, some municipalities sometimes commission a waste disposal company to have the beaches cleaned, if necessary. Others do the beach cleaning themselves. Sometimes external waste management companies are called in as support when large amounts of beach wrack have to be dealt with in a short time. In contrast, the "usual daily emergence" is dealt with by the municipality's own workforce and machinery.



Figure 2.2 Beach cleaning with an amphibious vehicle (Sassnitz, Germany, April 2019)

2.2.2 Amphibious vehicles

In April 2019, we did a beach cleaning trial with an amphibious vehicle ("Truxor", → Fig. 2.2).

This flexible vehicle can drive on tracks and swim on the water. It can be equipped with various attachments and tools to carry out the most diverse work on lakes and ponds. The available equipment includes various cutters, pumps, rakes, screens, skimmers, spreaders, diggers, milling equipment, choppers, rams, as well as shovels, grabs and forks. The overall capacity of the system is suitable for its primary purpose, i.e. maintenance of lakes and ponds. Still, for the efficient removal of the beach wrack from tourist beaches, the vehicle does not perform better than a wheel loader regarding the cleaning quality, the cleaned area per hour and the contamination of the beach wrack with sand.

The ability to swim may be an advantage sometimes. Still, since harvesting beach wrack from the shoreline before it reaches the dry ground is not allowed in Mecklenburg-West Pomerania, this technical advantage doesn't differ.

2.2.3 Specialized beach cleaning machinery

Special beach cleaning machines, such as the "Beachtech" series from the Kässbohrer Geländefahrzeuge AG (→ Fig. 2.3), are available on the market. These are primarily designed to remove cigarette butts, bottle caps, etc. from sandy beaches and are not suitable for removing beach wrack in large quantities. A discussion with the company's technical field service in February 2019 showed a possible interest in cooperation in developing such technology, and the absence of available technical solutions nowadays.

2.3 Other available biomasses for co-treatment

The main scope of this case study was the evaluation of biochar production from beach wrack by using the VTC ("vapo-thermal carbonization") treatment system. Before the CONTRA project started, it became clear that a VTC system to be created exclusively for the treatment of beach wrack would be too expensive both to build and operate in an economically feasible way.

Experience has shown that various other biomasses can be co-treated in VTC systems along with the beach wrack without any problems. In general, all biomasses that are usually treated at compost and biogas plants are also suitable for VTC systems. The same can be said for leftovers from composting and fermentation plants, such as the digestate and the coarse fraction from compost



Figure 2.3 Beachtech 2000 [Kässbohrer Geländefahrzeug AG]

screening after the respective treatment.
We have assessed suitable biomasses for co-treatment (like a green-and-garden waste, food residues from hotels and restaurants, roadside green waste, etc.) that could be available in the case study area. We conducted three surveys (January 24th, 2019, July 18th, 2019 and February 27th, 2020) by mail and email involving a total of 59 waste management companies, composting plants and municipalities in Mecklenburg Western Pomerania. However, the responses were relatively sparse, and in no way representative for the size of the region.
As we were unable to obtain meaningful data on the available amount of biomass that could be treated along with beach wrack, we decided to use a different approach for dimensioning the appropriate size of a VTC plant for the economic part of the case study. Therefore, we calculated a comparatively small annual throughput for a showcase plant's design and the associated profitability calculations. Using this approach, we hope to be on the safe side since, if the actual quantities turn out to be larger, this can only improve the plant's economic efficiency.

2.4 Biochar applications and the VTC process

2.4.1 The VTC process

With Vapothermal Carbonization (VTC), KS-VTCtech GmbH has developed a very robust batch process that can convert any biomass into a long-term storable and high-calorific product "biochar" (a more scientific term is "biomass carbonate").
Biochar is a collective term for various types of carbonized biomass that can be produced in different ways. Hydrothermal and Vapothermal Carbonization, torrefaction, and pyrolysis are technically different processes with different reaction conditions and temperatures. Still, they are all essentially aimed at producing higher calorific value materials from more or less fresh biomass.



Figure 2.4 an experimental VTC reactor

The VTC process is a thermo-chemical process, in which the natural formation of coal ("coalification") is reproduced within a few hours by using high pressure and heat. During the process, the relative carbon content of the biomass is increased at 220 °C and 23 bar in a pressure vessel with the reaction time of about 3 hours. VTC is not susceptible sensitive to contaminants, hence the input biomass does not have to be pretreated.

2.4.2 Treatment methodology

The respective sample was filled into the reactor (→ Fig. 2.4) along with an excess amount of water. Then the system was heated up. When the reaction chamber reached the temperature of 220 °C, the timer was set for 3 hours, and after completion, the steam was released from the test reactor. The sample was removed and left to cool. Then it was packed and delivered to the laboratory for analysis.

2.4.3 Biochar and ways of its utilization

The resulting biochar can be used as a replacement for fossil fuels, like lignite and hard coal at thermal power plants, cement plants, and other industrial combustion processes. The quality of biochar (calorific value, carbon content, ash content) can be influenced to a certain extent by the reaction time, but it mainly depends on the input biomass. Usually, the biochar in the range between lignite

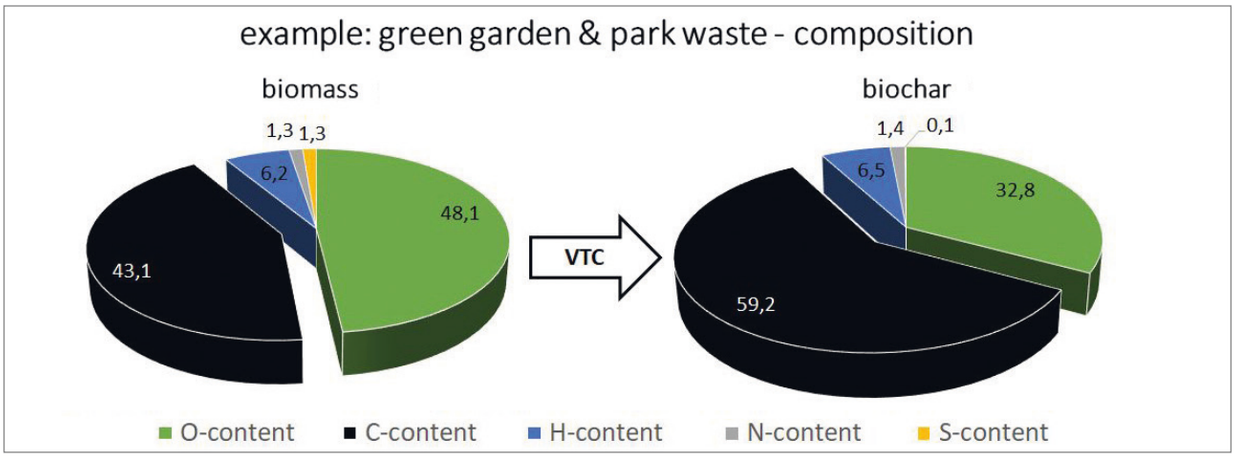


Figure 2.5 carbon proportion change during the Vapothermal Carbonization

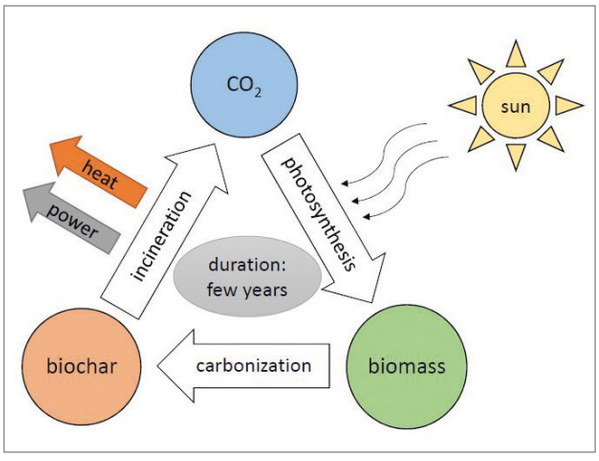


Figure 2.6 short-term carbon cycle

and hard coal can be reached within economically viable reaction parameters.

During the VTC process, the relative proportion of carbon in the biomass increases (→ Fig. 2.5) by thermal splitting off other atoms and molecules from the biomass. Around 700 kg of dry biochar remains from 1 ton of the input organic dry matter.

In addition to hydrogen and oxygen, nitrogen, sulfur and other elements of the biomass are also driven out of the molecules, which means that the process also produces water (steam) and various other secondary compounds in addition to the biochar. Inert components (ash, stones, sand, metal parts, etc.) are not affected by the process, and leave the reactor in the same way as they have entered it with the biomass.

The quality of biochar strongly depends on the composition of the input biomass. Biomass with a high ash content leads to biochar with a correspondingly high ash content, which harms the product's calorific value.

2.4.4. Biochar is carbon neutral

Since the biochar is made from "fresh" biomass, it can be considered a carbon-neutral fuel compared to fossil coal. It doesn't produce any additional CO_2 in short-term scale. The CO_2 released during the combustion of biochar has been removed from the atmosphere in recent years by photosynthesis during the biomass growth used for producing the biochar. In that context, the biochar use is a closed short-term carbon cycle (→ Fig. 2.6).

2.4.5 Marketability

The subject of pricing carbon emissions has become more and more into the focus of economic considerations during the last years. Most recently, a national system for carbon emission pricing was created by the German Government.

In December 2019 Germany's federal and state governments agreed to fix the price for CO_2 emissions at the rate of EUR 25 per ton of CO_2 starting from January 2021. After that, the price will gradually increase each year until it reaches EUR 55 in 2025. A price corridor between EUR 55 and EUR 65 shall then apply for the year 2026.

The details are regulated in the Law on a national certificate trading for fuel emissions – "Gesetz über einen nationalen Zertifikatehandel für Brennstoffemissionen (Brennstoffemissions-handelsgesetz – BEHG)". Solid fuels, such as coal, will be included from 2023 onwards. Therefore, the use of fossil coal will become correspondingly more expensive for consumers.

When lignite is burned, around 2.7 tons of CO_2 are released per ton of lignite, while in hard coal the emission factor is around 2.2 tons of CO_2 per ton of coal. Therefore, the use of fossil coal will become much more expensive, as shown in → Table 2.1.

year	2023	2024	2025	AS OF 2026
CO_2 emission price	35 €	45 €	55 €	55–65 €
Additional price per t: lignite	94.50 €	121.50 €	148.50 €	148.50–175.50 €
Additional price per t: hard coal	77.00 €	99.00 €	121.00 €	121.00–143.00 €

Table 2.1 German emission allowances and coal emission prices for 2023 [§10 BEHG]

Since the emission price will be paid for by the distributor of the coal (coal wholesaler or coal importer) in the first place, it is to be expected that these costs will be added directly to the sales price of the corresponding coal type. Thus, consumers will not have to deal with a complex emissions trading system, but they will feel the rise in solid fuel prices after 2022.
By then at the latest, the demand for alternative solid fuels, such as biochar, should increase significantly, since due to its material properties, carbon-neutral biochar is suitable for substituting fossil coal in co- or mono-combustion systems.

2.5 Properties of biochar from beach wrack

Since KS-VTCtech GmbH deals with the application of VTC, the biomass experimented within this case study (beach wrack and other biomasses suitable for co-treatment) was treated accordingly.

2.5.1 Biomass pretreatment and storage

Most samples were collected in 2019 and were carbonized freshly. Some were dried first, and some had already been collected in 2017 and 2018, then dried and stored. Since no significant systematic differences in the properties of the biochar, depending on previous drying or more extended storage, were observed in the course of the study, an evaluation of different pretreatment or storage methods was not carried out.
However, from experience we know that the carbonization reaction essentially influences the composition of the organic substance in the biomass; the inert components (sand, stones, ash, clamshells) contained there, leave the carbonization reactor unchanged.
Since the carbonization of the biomass is carried out to produce a high quality high calorific value biochar as a substitute fuel for combustion processes, the treated biomass should contain the highest possible proportion of organic dry matter before the carbonization process.
All above leads to the conclusion that biomass should be stored so that no composting or fermentation reactions can occur, since these also consume a proportion of the organic substance and, therefore, lead to a lower calorific value in the biochar.

2.5.2 Relevant parameters

Depending on the technical design of a combustion furnace (lignite/hard coal/biomass heat-and-power plant, cement plant, steel plant, etc.), different fuel parameters can be more or less relevant for the suitability of a particular fuel.
Since there was no focus on specific combustion technology, the suitability of beach wrack for the production of biochar was examined in general. Therefore, we limited ourselves to a few particularly relevant parameters when examining the biochar produced. The main parameters of the biochar are its calorific value and ash content.

Calorific value

Suppose biochar is produced as a substitute fuel. In that case, the product's essential property is undoubtedly its calorific value because it characterizes the specific energy released when a substance is burned. The calorific value depends on the chemical composition of the fuel, and it is also influenced by the material moisture and the mineral content (inert substances, ash content). Since the fuel's moisture content can be directly influenced relatively easily by drying, it will not be further considered here. Further, we put attention to the calorific value based on the dry substance.

Ash content

The ash content of fuel has a considerable influence on the calorific value, since the inert part of the fuel does not contribute to the combustion energy, but comes mixed with the fuel. Accordingly, it reduces the nominal calorific value of a fuel linearly, when considering calorific value per unit weight.
The incineration ash (i.e. the mineralized residue from the chemical conversion of the actual fuel) is the useless residue after the combustion process.

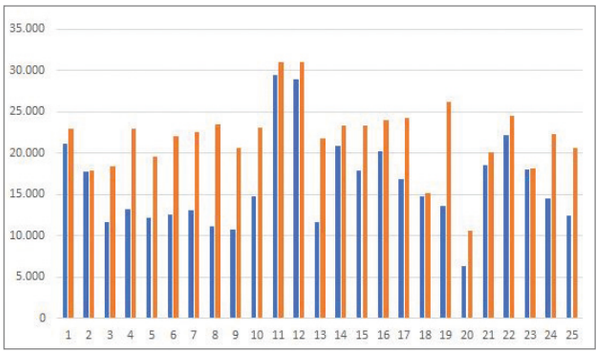


Figure 2.7 Calorific value [KJ/Kg] comparison chart (25 samples), biomass and biochar, blue – the lower calorific value (dry matter), brown – the lower calorific value (dry matter without ash).

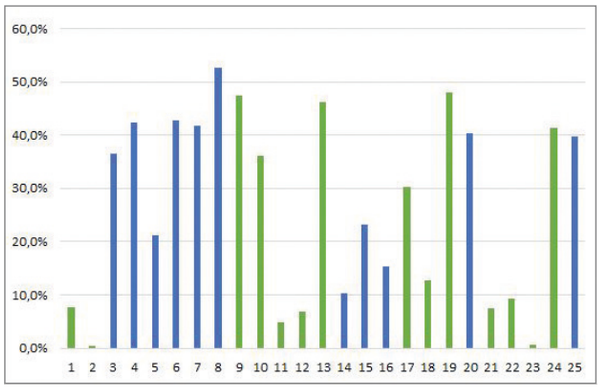


Figure 2.8 Ash content comparison chart (dry matter proportion, 25 samples), green – land-based biomass (wood, bio waste, food waste, green & garden waste, etc.), blue – marine biomass (beach wrack, algae, seaweed and reed).

The expected amount of incineration ash is relevant for the discharge system of an incineration plant.

2.5.3 Main analytic results

Concerning the calorific value and the ash content of the biomass used and the biochar produced, the following data was obtained from the analysis of 25 samples (→ sections 2.6.4, Fig. 2.7 and 2.6.5, Fig. 2.8). The samples 1, 2, 9–12, 17–19, 21-24 (14 samples) present the biochar made from land-based biomass, the samples 3–8, 14–16, 20, 24, 25 (11 samples) present the biochar made from marine biomass.

2.5.4 Calorific value results

All examined samples' calorific value range between about 18 MJ/kg and 26 MJ/kg (→ Fig. 2.7) that is approximately the spectrum between dry wood and hard coal. There is no significant difference between marine biomass (beach wrack, seagrass, algae, etc.) and land-based biomass (garden waste, wood, organic waste, etc.) to be observed.
Exceptions are the significantly higher calorific value of food waste (samples 11 + 12), probably due to the high fat's content, and the lower calorific value of the digestate and the material from torrefaction.
It could be proposed that the result in the case of carbonized digestate (sample 18) was obtained due to the fact that most of the organic matter was already broken down during fermentation. Still, it is questionable, as the fermentation should be recognizable by a comparatively high ash content, which was not the case. However, it may also be due to a measurement error or contamination of the sample.
The low calorific value of the material from torrefaction (sample 20) is probably because the torrefaction is essentially based on a pyrolytic decomposition of the biomass. Therefore, a larger part of the process emerges as a gas with a calorific value higher than during the VTC. However, it is needed to cconsider that here only the solid residue was examined but not the pyrolysis gas.
All the above indicates that marine biomass (and thus also beach wrack) is also suited for the production of biochar using the VTC process, as land-based biomass is.

2.5.5 Ash content results

The results (→ Fig. 2.8) show a comparatively high ash content in the samples of marine origin. Exceptions are the samples made from reeds (14) and the two mixtures of algae and wood (15, 16). This is probably because of the collection technology described in the previous chapters.
In contrast to the marine biomass obtained from beach cleaning, reeds can be harvested very clean, and the algae from samples 15 and 16 were fished from the surface water near the beach before they had direct contact with the beach itself. In addition, these samples were mixed with wood, which already has low ash content and, therefore, also reduces the average ash content in the mixture.
There are also samples of biomass produced on land that typically have a high ash content. This applies in particular to samples from biowaste (9, 10, 13), and digested and liquid manure (17, 19). In the case of biowaste, the cause is probably the lack of selectivity in the collection (soil and sand in the organic waste bin), while in the case of digestate it is mainly due to the fermentation that has already taken place, which also mineralizes biomass.
The sample biochar from mixed wood (24) also shows a very high ash content, but this cannot be explained by an improper collection or a mineralizing

INPUT	amount per year [Mg/a]	dry matter content [%]	bulk density [Mg/m³]	ash content [%]	dry matter [Mg/a]	ash [Mg/a]	organic dry matter [Mg/a]	water [Mg/a]
Green garden waste	15,000	50 %	0.4	6 %	7,500	450	7,050	7,500
Food waste	3,000	25 %	1.0	5 %	750	38	713	2,250
Breach wrack	1,000	20 %	1.0	40 %	200	80	120	800
Total	19,000	44.5 %	0.53	7.6 %	8,450	568	7,883	10,550

Table 2.2 input fractions for VTC treatment plant

pretreatment of the sample. This is more likely to be due to contamination after carbonization.
The carbonization itself also increases the relative ash content of the biochar produced, but not to the extent that would explain a measured value of over 40 %.

2.6 VTC plant technical design and estimated investment costs

2.6.1 VTC plant size

For the calculations presented in the following chapters, we assume an annual treatment volume of 1,000 t of beach wrack, 3,000 t of food waste from restaurants and hotels, and 15,000 t of green garden waste with properties as shown in → Table 2.2.
The amount of material to be carbonized (green waste, food residues, beach wrack) on the Island of Rügen is expected to be at least 19,000 Mg/a. Reliable data regarding the composition of the material to be carbonized is not yet available and therefore the input-material stream is assumed to be consistent over the years of plant operation.
A VTC system with a reactor volume of 48 m³ working in 3 batches per day is required to treat this input mix. Therefore, the plant has to be operated in two daily shifts. For energy efficiency reasons, a VTC treatment plant comprises at least two reactors. To make the given system as simple and therefore inexpensive as possible, a VTC plant consisting of 2 reactors, each 11 m long, is considered in this calculation.
Figure 2.9 shows a possible VTC plant layout corresponding to the case study conditions.

2.6.2 Summary of all analytic results

The table on the following page shows an overview of all results from laboratory analysis:

2.6.3 Estimated investment costs

The estimated investment costs include the required plant technology for the carbonization process, as well as for the drying and screening of the biochar. Mobile devices, such as wheel loaders that are required to operate the system, are taken into account. Concrete and building works are not included either.
A VTC treatment plant, like the one shown above, will add up to approximately EUR 3,350,000.

2.7 Legal framework, plant operation permission and conditions

2.7.1 German Waste Law and the definition of waste

According to the German Waste and Recycling Law (*"Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz – KrWG)"*), waste includes all substances or objects that their owner discards, wants to discard or has to discard. [§3 (1) KrWG].
The producers or owners of waste are obliged to recycle their waste. The recycling of waste has priority over its elimination [§7 (2) KrWG]. The obligation to recycle waste is to be met, insofar as this is technically possible and economically acceptable, particularly for a recovered substance or energy having a market, which already exists or can be created.
Waste recycling is defined as technically possible, even if pretreatment is required. Economic

no.	sample type	remarks / additional information	volatile matter	fixed carbon	ash content	higher calorific value [kJ/kg]		lower calorific value [kJ/kg]	
			% of wet mass	% of wet mass	% of dry mass	dry matter	dry matter w/o ash	dry matter	dry matter w/o ash
1	lignite	from "Lausitzer Revier"	52.7 %	31.7 %	7.7 %	22.191	24.033	21.144	22.898
2	wood	Biomasse Holz HOST	78.7 %	13.7 %	0.5 %	19.383	19.589	17.749	17.838
3	mixed beach wrack	Biomasse Treibsel	50.4 %	11.8 %	36.6 %	12.575	19.839	11.657	18.392
4	biochar from mixed beach wrack	Biokohle Treibsel	40.0 %	11.3 %	42.3 %	13.940	24.187	13.210	22.921
5	seaweed (2017)	biomass	58.6 %	12.5 %	21.2 %	12.871	20.715	12.138	19.565
6	seaweed (2017)	biomass	37.9 %	13.2 %	42.7 %	13.295	23.262	12.589	22.029
7	seaweed (2018)	biochar	42.5 %	13.2 %	41.7 %	13.885	23.831	13.153	22.576
8	seaweed (2019)	biochar	32.9 %	15.3 %	52.6 %	11.827	24.982	11.096	23.439
9	biochar from biowaste	leftovers from composting plant	37.6 %	17.3 %	47.4 %	12.740	24.243	10.798	20.552
10	biochar from biowaste	household biowaste	46.6 %	15.0 %	36.1 %	16.605	25.961	14.741	23.046
11	biochar from food waste	unprocessed food waste	73.7 %	12.4 %	4.9 %	31.299	32.917	29.413	30.933
12	biochar from food waste	processed food waste	74.7 %	28.0 %	6.8 %	30.812	33.060	28.915	31.024
13	biochar mixed biowaste	households & composting plants	39.5 %	32.2 %	46.1 %	13.667	25.484	11.666	21.772
14	biochar from reed		57.9 %	34.1 %	10.4 %	21.662	24.167	20.931	23.351
15	biochar from wood & algae	50 % wood + 50 % mixed algae	39.6 %	22.1 %	23.3 %	18.588	24.231	17.869	23.295
16	biochar from wood & algae	25 % wood + 75 % mixed algae	45.4 %	11.2 %	15.3 %	20.997	24.805	20.260	23.934
17	biochar from digestate	from dry fermentation plant	42.7 %	10.9 %	30.2 %	17.839	25.662	16.897	24.312
18	digestate	from dry fermentation plant	17.4 %	11.8 %	12.8 %	15.701	16.134	14.725	15.131
19	biochar from manure	HTC biochar from manure (kettle)	36.8 %	26.0 %	48.0 %	13.610	26.183	13.610	26.183
20	biochar from beach wrack	from torrefaction	44.1 %	9.6 %	40.4 %	7.029	11.862	6.298	10.635
21	green & garden waste	biomass	70.0 %	10.6 %	7.5 %	19.695	21.311	18.567	20.091
22	biochar from green & garden waste	biochar	59.9 %	0.0 %	9.3 %	23.318	25.722	22.184	24.472
23	mixed wood	biomass	78.7 %	0.0 %	0.5 %	19.483	19.589	18.027	18.124
24	biochar from mixed wood	biochar	44.4 %	0.0 %	41.4 %	15.279	23.494	14.458	22.244
25	bio char from algae	algae from Sellin, April 2019	47.0 %	0.0 %	39.8 %	13.155	21.849	12.424	20.636

Table 2.3 analytic results of biomass and biochar samples (with ash – without (w/o) ash)

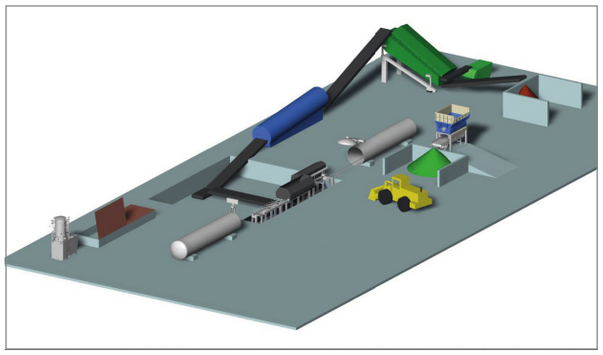


Figure 2.9 Layout example of a VTC treatment plant (VTC 2-11-8) with a capacity of 150 m³/day (reserve 150 m³/day).

acceptability exists, if the costs of recovery are not disproportionate to the costs that would have to be borne by waste disposal [§7 (4) KrWG].
Therefore, when a community or municipality cleans its beaches from beach wrack to keep tourists happy, it legally creates (and takes possession of) a new waste stream that has to be monitored and treated accordingly.
The amount of waste has to be documented. Its transportation and treatment have to be monitored. It can only be carried out by certified waste handling companies or service providers (Entsorgungsfachbetrieb) [§56ff. KrWG], and the final disposal has to be verified. This makes beach wrack collection and disposal complicated and expensive for German municipalities.
Since the dumping of waste in the Baltic Sea is illegal, beach wrack cannot be pushed back into the sea. However, suppose the sea should fetch back the washed-up material on its own, for example, simply due to a wind direction change. In that case, this is a legally unproblematic natural cycle, provided that the material was not touched in the context of beach management.
Many communities take advantage of this fact, at least outside of the tourist season, and hope that the washed-up material will disappear on its own in this way. Of course, this also applies to the many beaches, where there is no beach cleaning done anyway.

2.7.2 Treatment and disposal

Collected beach wrack must be properly disposed of, and depending on the level of pollution (e.g. heavy metals) there are several ways of doing it.
On the Island of Rügen, for example, the beach wrack is sometimes used in agriculture as fertilizer. It has been granted after the special permit if low pollutant content was proven.
If this is not the case, the material must be taken to an appropriately certified disposal facility (composting or fermentation facility, incineration, etc.). Recycling at a carbonation plant is also possible here.
Since all these systems have considerable operating costs and are usually run as private companies, beach cleaning entails the actual costs for collection and transportation and the related disposal costs. Although the problem has been known for many years, there is still no cost-effective, approvable, and scalable disposal method.

2.8 Economic feasibility

This case study aims to develop an example of an economically feasible showcase for the creation and operation of a VTC treatment plant to produce biochar, as a solid fuel from beach wrack mixed with other locally available biomasses.
It was obvious from the start of the project that 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. One possible option was to set up one or more beach wrack storage facilities on the island to optimize the transport routes for the biomass. Due to the island's size and the fact that the vast majority of the beach wrack occurs on the east coast, this interim storage facility will be avoided for economic reasons.
The area around Sassnitz could be a good location for a central treatment facility concerning the logistics of beach wrack. A more central location on the island, e.g. in the area of Bergen, could also be a good choice, considering that the other biomass to be co-treated will probably be delivered from all over the island. Because of its small impact on the overall economic performance, the exact location of the treatment plant will not be considered any further. The same applies to transport costs for the produced biochar since the location of possible biochar customers is yet to be determined.

2.8.1 Plant operation

The delivered biomass is weighed and temporarily stored on the factory premises. It is then visually inspected for coarse contaminants and filled into one of the carbonation reactors using a wheel loader.
During the reaction, the condensate that forms is regularly discharged from the reactor and cooled in a flash tank with a heat exchanger. The cooled condensate is pre-cleaned in a chamber filter

press, as a precoat filter, using flocculants to reduce the amount of dirt. Then it has to be cleaned at a wastewater treatment plant. Since the pressed suspended solids are fine biochar particles, the press cake can be added to the biochar produced and does not have to be disposed of separately.
After the reaction is completed, the reactor is shut down, and the contained steam is used to preheat another freshly filled reactor. After an equilibrium between the reactors is reached, the remaining steam from the first reactor is passed into the flash tank, where it is cooled down to below 100 °C.
As soon as the finished reactor reaches the atmospheric pressure, it can be opened and emptied. It is then refilled with the next batch of biomass and reheated.
The resulting raw biochar is then dried in a continuous dryer, operated with the waste heat from the flash tank. Afterwards, the dried biochar is treated in a 3D-vibrating screen to remove impurities, such as bottle caps, clamshells and stones.
The refined biochar can then be loaded and sold. Further treatment, for example with a pellet or briquette press, is also possible.

2.8.2 Economic assumptions

The following calculations are based on the biomass quantities and its composition (→ Tables 2.1 and 2.2), as well as the estimated investment costs from section 2.6.
The economic assessment was made using the following additional assumptions:

- Acceptance prices for the disposal of biomass ("gate fee"): 40 EUR/t for green-and-garden waste, and 50 EUR/t both for food leftovers ("restaurant waste") and beach wrack.
- The customer's purchase price for lignite is assumed to be 75 EUR/t (as a competitor for pricing our biochar).
- The lignite emission factor is 2.7 t of CO_2 per t of lignite. An annual price increase of 2 % is calculated on all costs and revenues.
- A 30 % discount on the competing lignite price is granted (biochar is sold 30 % cheaper than competing lignite) to achieve a cost advantage.
- The funding for plant construction and operation is calculated in the form of an annuity loan with 25 % equity, 3 % interest and a run-time of 10 years.
- The plant's lifetime is considered to be 12 years, starting from 2023.
- The price for heat energy (for steam production) is assumed to be 45 EUR/MWh (natural gas).
- The electricity price for operating the plant is assumed to be 180 EUR/MWh.
- Water for the steam generator (tap water including full desalination) is calculated at 2.63 EUR/m³.
- Wastewater disposal costs for pretreated (with flocculants and chamber filter press) wastewater from the VTC is calculated at 5 EUR/m³.
- Maintenance: a flat rate of 4 % of the plant investment costs per year.
- Personnel: 3 plant operators / wheel loader drivers spread over 2 shifts (3 x 35,000 EUR/a), plus 25 % administration fee.
- Other costs (insurances, etc.): 5 % of all other costs.
- Transport costs for biochar are not calculated since the customer location is unknown.

2.8.3 Long-term economic calculations

Based on the knowledge gained, and the assumptions described, a long-term economic feasibility assessment was carried out. The result over the considered operating period of 12 years, starting with the year 2023 (first year of operation) is shown in → Table 2.4.

2.9 Conclusions

The total annual amount of beach wrack in the case study area could not be precisely determined, as the municipalities or districts collect no official figures. The absence of reliable data regarding the amount of beach wrack is surprising, as beach wrack is legally a waste under German Law as soon as it is picked up to clean the beaches.
However, even without reliable official data about the total emerge of beach wrack, all affected municipalities face a significant challenge at least during the tourist season, since the majority of beach tourists regard beach wrack as a nuisance.
The existing machines for collecting beach wrack consist of conventional construction and agricultural ones, while there is no technology specifically designed for removing large quantities of beach wrack.
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 inert material (sand, clamshells, etc.), which harms the quality of the biochar produced.
An example of a production plant was developed, which would be able to treat the estimated amount

of beach wrack together with other biological waste from the Island of Rügen. An accompanying profitability calculation underlines the possibility of an ecologically and economically safe plant construction and operation.

Whether this would be just as economically lucrative in other countries around the Baltic Sea without the German national carbon emissions trading law remains to be checked in each case.

			1	2	3	4	5	6	7	8	9	10	11	12
Year of operation	**unit**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**
Carbon emmission fee	[€/t CO2]	0 €	35 €	45 €	55 €	60 €	60 €	60 €	60 €	60 €	60 €	60 €	60 €	60 €
Annual price increase lignite	[%/a]	0%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Price for lignite	[€/t lignite]	75 €	77 €	78 €	80 €	81 €	83 €	84 €	86 €	88 €	90 €	91 €	93 €	95 €
Price for lignite incl. Emissions	[€/t lignite]	75 €	171 €	200 €	228 €	243 €	245 €	246 €	248 €	250 €	252 €	253 €	255 €	257 €
Discount on competing prices	[%]	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%	30%
Sales price for biochar	[€/t biochar]	53 €	120 €	140 €	160 €	170 €	171 €	173 €	174 €	175 €	176 €	177 €	179 €	180 €
Revenues from biochar	**[€/a]**		**836.967 €**	**976.608 €**	**1.116.400 €**	**1.190.267 €**	**1.198.214 €**	**1.206.320 €**	**1.214.588 €**	**1.223.022 €**	**1.231.624 €**	**1.240.398 €**	**1.249.347 €**	**1.258.476 €**
Annual gate-fee increase (biomass)	[€/a]		2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Gate-fee green & garden waste	[€/t biomass]	40 €	41 €	42 €	42 €	43 €	44 €	45 €	46 €	47 €	48 €	49 €	50 €	51 €
Gate-fee leftover food waste	[€/t biomass]	50 €	51 €	52 €	53 €	54 €	55 €	56 €	57 €	59 €	60 €	61 €	62 €	63 €
Gate-fee beach wrack	[€/t biomass]	50 €	51 €	52 €	53 €	54 €	55 €	56 €	57 €	59 €	60 €	61 €	62 €	63 €
Revenues from gate-fees	**[€/a]**		**816.000 €**	**832.320 €**	**848.966 €**	**865.946 €**	**883.265 €**	**900.930 €**	**918.949 €**	**937.328 €**	**956.074 €**	**975.196 €**	**994.699 €**	**1.014.593 €**
Total revenues	**[€/a]**		**1.652.967 €**	**1.808.928 €**	**1.965.366 €**	**2.056.213 €**	**2.081.479 €**	**2.107.250 €**	**2.133.537 €**	**2.160.349 €**	**2.187.698 €**	**2.215.593 €**	**2.244.047 €**	**2.273.069 €**
Annual increase (all costs)	[%/a]	0%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
Financing of investment costs	[€/a]	-838.769 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	-294.988 €	0 €	0 €
Heat energy	[€/a]	-222.891	-227.348 €	-231.895 €	-236.533 €	-241.264 €	-246.089 €	-251.011 €	-256.031 €	-261.152 €	-266.375 €	-271.702 €	-277.136 €	-282.679 €
Electrical energy	[€/a]	-97.200	-99.144 €	-101.127 €	-103.149 €	-105.212 €	-107.317 €	-109.463 €	-111.652 €	-113.885 €	-116.163 €	-118.486 €	-120.856 €	-123.273 €
Feed water for steam generator	[€/a]	-16.722	-17.057 €	-17.398 €	-17.746 €	-18.101 €	-18.463 €	-18.832 €	-19.209 €	-19.593 €	-19.985 €	-20.384 €	-20.792 €	-21.208 €
Waste water from VTC	[€/a]	-79.297	-80.883 €	-82.501 €	-84.151 €	-85.834 €	-87.551 €	-89.302 €	-91.088 €	-92.910 €	-94.768 €	-96.663 €	-98.596 €	-100.568 €
Maintenance costs	[€/a]	-134.000	-136.680 €	-139.414 €	-142.202 €	-145.046 €	-147.947 €	-150.906 €	-153.924 €	-157.002 €	-160.142 €	-163.345 €	-166.612 €	-169.944 €
Personnel costs	[€/a]	-105.000	-107.100 €	-109.242 €	-111.427 €	-113.655 €	-115.928 €	-118.247 €	-120.612 €	-123.024 €	-125.485 €	-127.994 €	-130.554 €	-133.165 €
Administration costs	[€/a]	-26.250	-26.775 €	-27.311 €	-27.857 €	-28.414 €	-28.982 €	-29.562 €	-30.153 €	-30.756 €	-31.371 €	-31.999 €	-32.639 €	-33.291 €
Other costs (insurance, etc.)	[€/a]	-48.795	-49.771 €	-50.766 €	-51.782 €	-52.817 €	-53.874 €	-54.951 €	-56.050 €	-57.171 €	-58.315 €	-59.481 €	-60.671 €	-61.884 €
Transport costs	[€/a]	0	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €	0 €
Total costs	**[€/a]**	**-838.769 €**	**-1.039.747 €**	**-1.054.642 €**	**-1.069.835 €**	**-1.085.332 €**	**-1.101.139 €**	**-1.117.262 €**	**-1.133.707 €**	**-1.150.482 €**	**-1.167.591 €**	**-1.185.044 €**	**-907.857 €**	**-926.014 €**
Annual surplus	**[€/a]**		**613.220 €**	**754.287 €**	**895.531 €**	**970.881 €**	**980.340 €**	**989.988 €**	**999.829 €**	**1.009.867 €**	**1.020.106 €**	**1.030.550 €**	**1.336.190 €**	**1.347.056 €**
Cumulative surplus	**[€]**		**-225.549 €**	**528.738 €**	**1.424.269 €**	**2.395.150 €**	**3.375.490 €**	**4.365.478 €**	**5.365.307 €**	**6.375.175 €**	**7.395.281 €**	**8.425.831 €**	**9.762.021 €**	**11.109.077 €**
Treatment costs per t of biomass (without consideration of gate-fee and biochar sale)			**-55 €**	**-56 €**	**-56 €**	**-57 €**	**-58 €**	**-59 €**	**-60 €**	**-61 €**	**-61 €**	**-62 €**	**-48 €**	**-49 €**
Overall treatment costs per t of biomass with consideration of gate-fee and biochar sale			**32 €**	**40 €**	**47 €**	**51 €**	**52 €**	**52 €**	**53 €**	**53 €**	**54 €**	**54 €**	**70 €**	**71 €**

Table 2.4 long-term economic calculations

Case study 3: Beach wrack as a compost material in landfill bio-covers (Wracover)



Authors: Guizani S.H., Busk T., Aldag S., Quintana C. O.

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: to 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, and methane mitigation was measured. Beach wrack compost was tested in a laboratory for compliance with standards for use in a biocover.

Staff involved: Sara Hillbom Guizani, Jacob Skjødt Nielsen

3.1 Location of the case study

The case study area is situated in Køge Bay, located in Eastern Zealand, Denmark, facing the Baltic Sea (→ Fig.3.1). Køge Municipality owns and manages two natural beaches: North Beach and South Beach (see Fig. 3.2). The total length of the managed beach is around 900 m. The management consists of regular cleaning of the beach during spring and summer seasons (see below section 2.2). The total coastline of Køge Municipality is around 12 km.

A discontinued landfill is located close to the Northern beach and marina in Køge Municipality. It is now a recreational area with a forest cover called "Tangmoseskoven" (see Fig. 3.3).

Køge Municipality has through the CONTRA project tested if beach wrack compost can be used at this discontinued landfill to mitigate methane emissions from the buried waste. The landfill has an area of around 10,000 m². A biocover, made with green cut material from gardens and parks, with an area of 1,200 m² was installed there to mitigate methane emissions.

3.2 The effect of beach wrack in Køge Municipality

The geographic location of the bay, wind conditions, shallow waters, and large seagrass meadows make the beaches in Køge Municipality prone to the accumulation of beach wrack. In 2017 and 2018, the managed beaches in Køge Municipality received on average 1,400–1,800 tons of beach wrack (wet weight). However, the yearly variations are high, local beach cleaning authorities have recorded as much as 14,000 tons in one year. The neighbouring municipalities along Køge Bay have similar high variation records in the amounts of beach wrack.

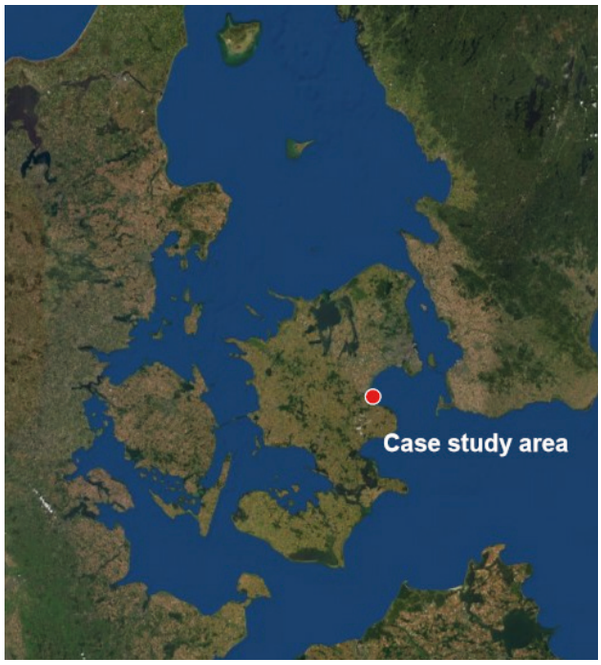


Figure 3.1 Location of case study 3 (CS3) area at the coast of Eastern Zealand, Denmark.

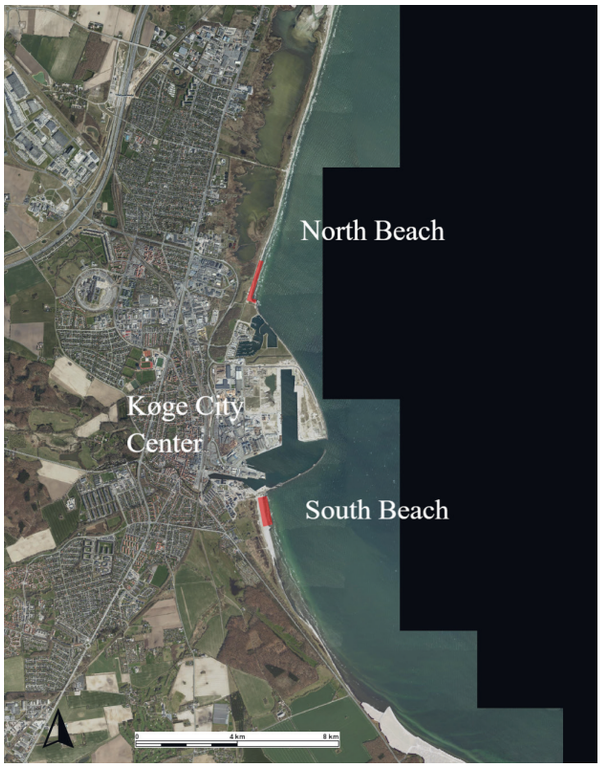


Figure 3.2 The areas (b) along the North and South Beach in Køge Municipality, where beaches are managed.

The samples collected by CONTRA project partner, University of Southern Denmark, from the managed South Beach in Køge in April–December 2019 show that dry weight in kg/m² of beach wrack ranges from approx. 25 kg to 380 kg per month. The species *Zotesra marina, Cladophora sp., Ceramium sp.,* and *Chaetomorpha sp.* are the most frequent macrophytes in relation to the total biomass (wet weight).
→ Figure 3.3 exemplifies how significant the amounts of beach wrack can be in Køge Municipality. The beach wrack creates a physical barrier between the beach visitors and the sea, making it difficult for them to go for a swim. Furthermore, beach wrack may give off a foul smell due to the microbial decomposition of the organic material. This happens, when torn off pieces of filamentous brown algae (*Pilayella litorallis*) accumulate in the water's edge. The problems with smell from these torn brown algae, also known in Danish as "fedtemøg", are a common problem throughout the coastal municipalities along Køge Bay. The smell is a great nuisance for residents and guests, who complain to the municipality if they think beach cleaning is insufficient.
Køge Municipality runs beach cleaning operations to keep the beaches free of beach wrack for tourists and residents and to avoid bad smells. The beach is cleaned every day from the 1st of May to the 30th of September for litter and beach wrack. Beach wrack is most commonly piled short-term, and the pushed back into the sea when the current allows it. This beach cleaning has a cost for the municipality. Due to the large amounts that wash up on the beaches of Køge Municipality, local authorities see beach wrack as a potential resource and are therefore interested in exploring recycling methods.

3.3 The tested technology

3.3.1 Biocover in Tangmoseskoven

In 2015 emission levels were measured in Tangmoseskoven forest showing methane emissions from the buried waste with certain hotspots with high emission levels. A technology to mitigate these emissions using compost is called a "biocover" (see Fig. 3.4).
Biocover is a technology that has been in use on several landfills internationally and in Danmark [Scheutz et al., 2014]. In 2014–2020 the Danish government financially supported experiments with biocovers on Danish landfills to mitigate emissions. The biocover in Køge Municipality is one of these experiments, contributing to the knowledge of this technology's mitigation potential. Biocover technology uses methane-oxidizing microorganisms found in compost to convert methane emissions from landfill waste to CO_2 and water [Kjeldsen and Scheutz, 2016]. Methane is a gas which has a

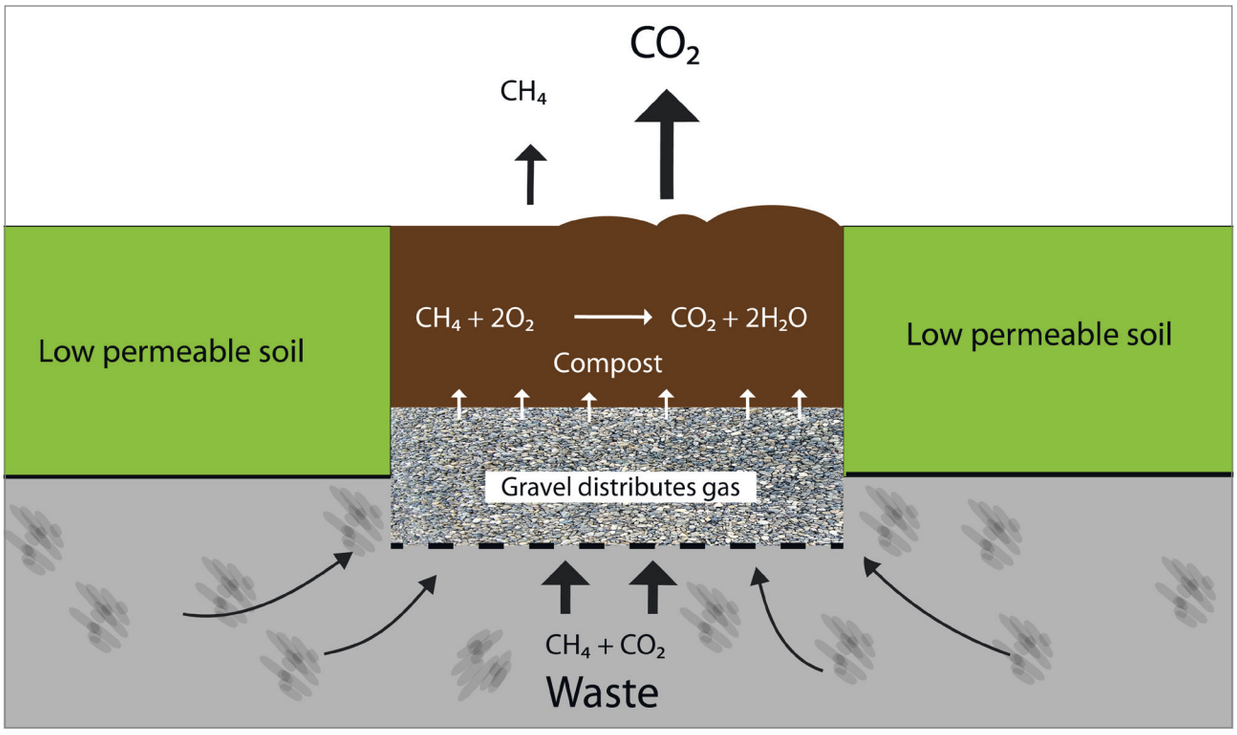


Figure 3.4 Biocover "window" system (after [Kjeldsen & Scheutz, 2014])



Figure 3.3 North Beach in Køge Municipality, May 2019

greenhouse effect 25 times larger than CO_2, and a biocover, therefore, contributes to decreasing the landfill's total greenhouse effect [Tværministriel Arbejdsgruppe, 2013].

A biocover consists of a gas-dispersal layer made up of gravel or crushed concrete placed over the landfill waste. A compost layer is added on top, either on the whole landfill or in "windows". As the original cover layer is often relatively impermeable soil, the landfill gas will migrate towards the biocover, where it will be converted to CO_2 (see Fig. 3.4).

The proposed project in Tangmoseskoven included three biocover windows with a total area of 1,200 m² and plugging of five boreholes of aprox. 30 cm in internal diameter. The project was estimated to have the potential of reducing methane emissions by 4 kg methane/hour for the area of Tangmoseskoven [NIRAS, 2016]. Tangmoseskoven is approx. 147,000 m².

A biocover was established in Tangmoseskoven in March 2020.

Due to challenges described in sections 3.5 and 3.6, this biocover was made using compost produced from a mixture of garden waste from households and parks according to the standard for use in biocovers [The Danish Environmental Protection Agency & DTU, 2018]. The compost used in this biocover did not include any beach wrack. Beach wrack compost was tested separately to see if it meets the standards for compost in a biocover (see section 3.3.2 and 3.3.3).

Biocover technology is in use in landfills in Denmark [Kjeldsen & Schuetz 2011, Pedersen et al. 2012], but the technology is still new. Therefore the emissions measurements after the installation of the biocover contribute to more precise estimations of methane emissions related to landfills, which will help develop best practices for mitigating emissions.

During the project planning period, two out of the three suggested biocovers were taken out of the project for reasons explained in section 3.5. The mitigation potential of the project, therefore decreased to 3.4 kg methane/hour for the area of Tangmoseskoven according to estimations.



Figure 3.5 The discontinued Køge Landfill – "Tangmoseskoven" and the biocover. The biocover is shown in red.

Measurements of methane emissions in Tangmoseskoven in September 2020 [FORCE Tehcnology, 2020] showed a decrease by 15 kg methane/hour compared to baseline emissions recorded in 2015 [NIRAS, 2015][1], namely from 17.2 kg methane/hour down to 2.2 kg methane/hour.

Several factors could affect this measurement, such as weather, temperature, atmospheric pressure, variations in methane production and screening methods [NIRAS, 2015; NIRAS, 2016; FORCE Technology, 2020]. Additionally, the baseline measurements were made in 2015, and thus the production of methane from the waste may have decreased over time. However, the decrease in methane emission for the area of Tangmoseskoven from 2015 to 2020 is significant (87 %). Thus indicating that the biocover including the plugging of the boreholes was effective in reducing methane emissions. Other studies have showed similar large reductions in emissisons after the establishment of a biocover [Pedersen et al., 2012]. It is estimated, based on a previous experiment, that the biocover itself is responsible for the reduction of approx. 60 % of these emissions reductions and the plugging of boreholes is responsible for the remaining 40 %[2].

3.3.2 Beach wrack compost

The purpose of this case study was to test the potential of using composted beach wrack in a biocover for landfills. A standard protocol [Kjeldsen and Scheutz, 2017, Table 2] was developed for the use of compost in a biocover.

In a study of compost samples from 13 Danish compost plants, it was concluded that, if intending to use compost made from any other material than garden waste, the material must be tested for use as a biocover against standards. It is essential for a biocover that the compost has an acceptable methane oxidation rate [Olesen et al., 2017]. The study of 15 compost samples, made from green cut waste concluded that the highest methane oxidation rates were from a compost, which had either been sieved on a fine sieve >15 mm or had composted over six months [Olesen et al., 2017].

Three samples (→ Table 3.1) of beach wrack compost were tested according to the standard protocol for biocover [Kjeldsen and Schuetz, 2017]. Two samples were from CONTRA project partner – Hanseatische Umwelt CAM GmbH. One sample was from Køge Municipality. Details of the samples can be found in → table 3.1.

3.3.3 Results of test of methane rates, respiration rates and quality criteria for compost used in biocovers

The three samples presented in → Table 3.1 were tested according to the protocol [Kjeldsen and Schuetz, 2017] for methane oxidation rate and respiration rate (→ Tables 3.3 and 3.4).

1 The baseline used here is 17.2 kg methane/hour. NIRAS 2016 used a baseline of 13.7 kg methan/hour. However, after conversations with the Danish Environmental Protection Agency it was agreed that 17.2 kg methane/hour was the most accurate baseline of total emissions.

2 NIRAS conducted an experiment concerning the temporary plugging of the 5 boreholes in Tangmoseskoven forest in 2019. The following measurement of emissions measured by FORCE Technology, showed a total methane emissions from the area of Tangmoseskoven to equal 9.9 kg/hour. This is 7.3 kg/hour lower than the baseline total emissions for 17.2 kg/hour, resulting in a reduction of 40 %. The result indicates that the existing natural cover of earth and vegetation in the Tangmoseskoven forest, contributes to oxidizing methane from the buried waste in the ground. Therefore the decision was made to permanently plug the boreholes, rather than establish a biocover on top. The total methane emissions measurement was conducted at different wind directions, but the assesment is that this should not affect the results significantly. This experiment was reported on by e-mail to the Nature Protection Agency.

SAMPLE 1 BEACH WRACK COMPOST HANSEATISCHE UMWELT	
From	Hanseatische Umwelt CAM GmbH
Contains	70 % green cut material/green waste and 30 % beach wrack (sand share 50 %–70 % by weight for beach wrack)
Maturity	5 months
Description of composting process and origin of materials	Beach wrack from the Island of Poel. Collected and processed in October 2019. The beach wrack was stored until May 2020 at Hanseatische Umwelt facilities and mixed with the fresh shredded green cut material. The greencut material origin: private households and municipalities collected green cut material in the Rostock County region, in a radius of about 50 km around the Hanseatische Umwelt facilities. The green waste material was provided to Hanseatische Umwelt in April 2020. The temperature was monitored continuously. The pile was turned every 14 days. Open windrow composting, turning by the excavator. No watering.
SAMPLE 2 GREEN CUT MATERIAL COMPOST	
From	Hanseatische Umwelt CAM GmbH
Contains	100 % green cut/green waste
Maturity	5 months
Description of composting process and origin of materials	The green cut material origin: private gardeners and municipalities collected green cut material in the Rostock County region. The Hanseatische Umwelt facilities. The green cut material was provided to Hanseatische Umwelt in April 2020. The temperature was monitored continuously. The pile was turned every 14 days. Open windrow composting, turning by the excavator. No watering.
SAMPLE 3 BEACH WRACK COMPOST KØGE MUNICIPALITY	
From	Køge Municipality
Contains	33 % green cut material/green waste, 33 % beach wrack, 33 % horse manure
Maturity	Three months
Description of composting process and origin of materials	The compost pile was set up with 50 % green waste and 50 % beach wrack in August 2020. However, the beach wrack contained large amounts of sand (50 %), and the green cut material did not contain enough phosphorus (as it was mainly large sticks) to allow for quick composting. Therefore, horse manure was added in September 2020. The beach wrack was from the beach in Køge Municipality, and the green cut material from Køge Municipality. The compost pile was turned and watered weekly. The temperature of the pile was also monitored weekly.

Table 3.1 Details of tested compost samples

The accepted values for use in biocover are:
- respiration rate <48 µgO2/g material (dry weight) per hour
- methane oxidation >20µg CH4/g material (dry weight) per hour

The samples were also tested for the parameters listed in (→ Table 3.2) that are defined as quality criteria for compost to be used in a biocover according to [Kjeldsen and Schuetz, 2017].

The results show that the two samples from Hanseatische Umwelt (sample 1 and sample 2) do not meet the criteria for methane oxidation rate and respiration rate. Sample 1 met only one of the quality criteria for use in biocover, see Table 3.2. An explanation for this may lie in the low level of organic matter, due to a high percentage of sand (50 %) in the sample. High sand percentage is a result of the waves and winds mixing this material into beach

wrack or the harvesting procedure, which scrapes off a few centimenters of the sand surface. The degradation processes reduced the biomass of the total sample of beach wrack compost causing a high density and low nutrient content. Additionally, the beach wrack used for sample 1 was collected from previous years, and thus the degradation was already at an advanced stage. Sample 2 fulfilled 5 out of the 8 quality criteria for use in biocover (→ Table 3.2).

PARAMETER	UNIT	ACCEPTED VALUES	SAMPLE 1 70 % GW + 30 % BW	SAMPLE 2 100 % GW	SAMPLE 3 33 % GW + 33 % BW+ 33 % HM
Dry density	g dry weight/l	260–520	812.3	632.9	153.6
Water content	g/g dry weight	0.3–0.5	0.22	0.30	2.12
Total porosity	% pore volume	60–80	37.5	51.3	88.2
Total nitrogen	mg/kg dry weight	> 5,000	4,300	7,000	11,875
NH4+-nitrogen	mg/kg dry weight	< 350	60.32	82.16	53.13
Acidity, pH	no unit	6.5-8.5	8.6	8.6	7.8
Organic matter as a loss on ignition	% of dry matter	>15 %	10.9	19.1	34.0
Dry matter	% of sample wet weight	50–80	81.8	76.9	32.0

Table 3.2: Results from samples compared to quality criteria for compost used in biocover according to [Kjeldsen & Schuetz, 2017], excluding criteria for methane oxidation and respiration. Red and green colors correspond to not fulfilled and fulfilled the biocover criteria, respectively. GW: green waste, BW: beach wrack, HM: horse manure.

SAMPLE	DAY 1	DAY 2	DAY 3	AVERAGE RATE	ACCEPTED FOR USE IN BIOCOVER
1 (container 1)	-265.95	345.06	NA	39.55	Yes
1 (container 2)	-368.07	297.71	13.67	-18.97	No
1 (container 3)	-525.25	367.77	-46.42	-67.97	No
2 (container 1)	77.67	36.81	57.97	57.48	Yes
2 (container 2)	28.4	NA	-99.19	-23.60	No
2 (container 2)	-97.34	-57.18	NA	-51.51	No
3 (container 1)	NA	NA	213.38	213.38	Yes
3 (container 2)	NA	NA	NA		Yes
3 (container 3)	231.41	NA	288.36	259.89	Yes
3 control (container 1)	NA	NA	9.94	9.94	No

Table 3.3: Methane oxidation rate in μ (measured in CH4/g material (dry weight)/hour).[3] The test was conducted according to the protocol in [Kjeldsen & Schuetz, 2017]. The methane oxidation rate (μ) accepted for use in biocover is less than 20 CH4/g material (dry weight)/hour. Red and green colors correspond to not fulfilled and fulfilled the biocover criteria, respectively.

3 Non applicable results for control samples with no added methane were removed from the table.

SAMPLE	DAY 1	DAY 2	DAY 3	AVERAGE RATE	ACCEPTED FOR USE IN BIOCOVER
1 (container 1)	59.69	NA	NA	59.69	No
1 (container 2)	NA	115.98	326.85	221.415	No
1 (container 3)	161.67	470.95	NA	316.31	No
2 (container 1)	NA	NA	NA		
2 (container 2)	70.52	63.47	59.94	64.64	No
2 (container 3)	NA	63.47	66.99	65.23	No
3 (container 1)	NA	NA	NA		
3 (container 2)	0.02	0.03	0.06	0.037	Yes
3 (container 3)	0.02	0.04	0.05	0.037	Yes

Table 3.4: Respiration rate in $\mu g/O_2/g$ material (dry weight)/hour. The test was conducted according to the protocol in [Kjeldsen & Schuetz, 2017].[4] The respiration rate accepted for use in biocover is less than 48 $\mu g/O_2/g$ material (dry weight)/hour.

The sample 3 from Køge Municipality fulfilled the requirements for the methane oxidation rate, and the respiration rate. Sample 3 meets 4 out of the 8 of the quality criteria for use in biocover, see Table 3.3. The results from the control sample 3 (container 1), see Table 3.3, however, indicated that the compost from sample 3 emitted methane. Active compost may stimulate methane-oxidizing bacteria, thus furthering methane conversion. However, this must not exceed the total methane oxidation rate, resulting in total methane emissions.

Sample 1, made using beach wrack, did not meet all quality criteria or have an accepted value of methane oxidation rate or respiration rate. Sample 3, made using beach wrack, did not meet all quality criteria but did have accepted values of methane oxidation rate and respiration rate. Sample 2, made from green cut waste, did not meet the quality critera or have accepted values of methane oxidation rate and respiration rate. Accepted methane oxidation rates are most significant for evaluating the ability of compost to convert methane from landfill waste. However, a compost must fulfill all criteria listed in [Kjeldsen & Schuetz, 2017] to be accepted for use in a biocover and ensure the emissions reduction effect. Overall, the results show that compost made using beach wrack can be suitable for use in a biocover as it can have an acceptable methane-oxidation rate, but more research is needed to understand its precise effect on methane-oxidizing bacteria and the proposed quality criteria.

3.4 Management-based obstacles

3.4.1 Collection, storage, and transportation of beach wrack for recycling

The Green Transition team from Køge Municipality was in an internal dialogue with the Department of Engineering and Buildings. This department is in charge of beach cleaning in Køge Municipality. The purpose was to identify guidelines for a consistent method of collecting and composting beach wrack using the machinery and facilities already available to the municipality. The technology and methods applied have proven to be challenging, as the current collecting and storing method is not properly designed for recycling of beach wrack.

The objective of the Department of Engineering and Buildings in Køge Municipality is to keep the shore clean of beach wrack and litter in the spring and summer seasons. The department collects the beach wrack in piles on site for short-term storage until it can be pushed back into the sea, when there is current. This method of collecting beach wrack can result in large amounts of sand in the beach wrack as the machines scrape sand into the beach wrack during collection. Therefore the beach wrack available to the municipality at the time was not optimal for composting.

4 Non applicable results for control samples with no added methane were removed from the table.

3.4.2 Availability of organic material and variations in beach wrack

Through the case study period, it was discovered that 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 municipality manages several green areas and parks within its territory, and thus regularly collects such waste. However, the availability of green waste is limited to the spring and summer seasons. Therefore, it was not possible to make beach wrack compost in winter 2019 and early spring 2020 before establishing the biocover in March 2020.

The amount of beach wrack on Køge Municipality's beaches is highly variable. Apart from monthly variations, there are also yearly variations as mentioned above in section 2.2. In this case study, it was a challenge to plan for the collection of beach wrack and green waste simultaneously, due to variations and seasonal limitations on the availability of these materials.

3.5 Administrative/legal obstacles

3.5.1 Establishing a biocover in a coastal recreational area

Establishing a biocover in a recreational area near the coast presented several challenges during the case study. The Green Transition team applied for permissions, as well as altered the designed project based on the requirements of the Danish Coastal Authority, the Danish Environmental Protection Agency, the Department of Environment, and the Department of Engineering and Building in Køge Municipality.

The Danish coast is regulated by the National Nature Protection Act, which upholds the coastal protection line. The coastal protection line is legislation that ensures that no changes are made to the Danish coast within 300 meters from the water's edge. It was therefore necessary to apply for a dispensation from the Nature Protection Act to establish a biocover in Tangmoseskoven. Dealing with a recreational area, it was also necessary to seek permission from the municipality. The municipality had several requirements to be incorporated into the project to ensure that the construction of the biocover did not damage the recreational area or introduce any invasive species through the compost. The municipality also set requirements for testing the soil at the landfill in Tangmoseskoven to ensure that contaminated soil was not brought to the surface, where it might get in contact with those visiting the area.

The precautions that were required by the municipality to construct the biocover without damage to the recreational area meant that one of the three biocover windows was removed from the project. The second biocover window was also removed, as it was discovered that the municipality had plans to pave over this area in the future.

3.5.2 The use of beach wrack as a natural resource

The case study has shown that the beach owner, such as the municipality, is allowed to remove or let others remove beach wrack from the shore. Beach wrack is not explicitly regulated by Danish law. However, if intending to sell or give away the beach wrack, as a soil improvement product, requirements for storing such products will have to be met, and requirements for use as soil improvement must be met and proven through testing, for instance a limit on the presence of heavy metals (Cadmium). For large scale composting or storage of beach wrack, this can be an obstacle, adding further costs.

3.6 Proposals for potential solutions to beach wrack recycling

3.6.1 Biocover as a recycling option

The case study demonstrated that a biocover with green waste that has been composted according to the recommended standard for biocovers [The Danish Environmental Protection Agency & DTU, 2018], is effective in reducing methane emissions from a landfill. Compost made with 30 % beach wrack has a potential to fulfil the criteria for use in a biocover. However, the % of sand was critical and the suitability of beach wrack compost may depend on the composting process, organic material and the species composition of the beach wrack. More tests are needed to determine when beach wrack compost can be used in a biocover.

3.6.2 Cooperation with local actors

The case study has demonstrated that, if intending to use composting as a recycling method, it is necessary to locate enough organic material to co-compost with the beach wrack. In the case study example, a total of 1,200 m^3 of compost material was needed for 1 biocover window. This amount will vary according to the size of the landfill and biocover. A municipality may have access to some

amounts of other organic material, but it may also be beneficial to cooperate with waste management companies with access to more organic material that can be co-composted with beach wrack.
Methods and machinery for collecting beach wrack used by municipalities are not optimal for later beach wrack recycling. One possible solution is to cooperate to a higher degree 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.

3.6.3.Other options for recycling beach wrack

The case study demonstrates that composting is one method of reusing beach wrack. However, high amounts of organic material are needed to compost the beach wrack. There may be other methods where a higher percentage of beach wrack is used directly in a new product. On the other hand, composting may be a possibility for using mixtures of beach wrack that are not easily recyclable into higher-value products.

3.6.4 More knowledge on seasonal beach wrack variations

The high seasonal and annual variations in the amount of beach wrack biomass make it more challenging to plan the collection and composting. Additionally, the production of compost needs to be timed to the availability of organic waste. More knowledge on the patterns in seasonal variation of beach wrack amounts is needed if intending to have a reliable supply of any beach wrack product. Similarly, knowledge on the seasonal species composition of the beach wrack is relevant for the products that only use components of beach wrack, such as eelgrass. The CONTRA project and its results are a good example of projects providing relevant knowledge on seasonal beach wrack variations at Baltic Sea beaches.

3.7 Conclusions

The biocover composed by 100% green waste, which met the compost standard [The Danish Environmental Protection Agency & DTU, 2018] was effective in reducing methane emissions from the old landfill in Tangmoseskoven. In the case study, the biocover along with the plugging of 5 boreholes reduced methane emissions at the landfill by 87%. Tests of compost with 30-33% beach wrack fraction showed that one out of two samples met the methane oxidation criteria required for application as a biocover [Kjeldsen & Schuetz, 2017]. These results are based on small sample size, and demonstrate that further research should be performed on which type of organic material stimulate and contribute to the presence of methane-oxidizing bacteria.
The case study shows that beach wrack can be composted as a recycling method, although it will make up only 30-33% of the total compost amount. This recycling option may be particularly applicable if beach wrack is mixed, and cannot be separated into macroalage and eelgrass fractions for direct reuse.
The case study has also shown that it can be difficult for a municipality to bear the cost of collection, storage, transportation and composting of beach wrack. Therefore municipalities chose the easier option of collecting beach wrack short-term, before pushing it into the sea. Additionally, the municipality may lack facilities and machinery for the task of carefully collecting beach wrack, so it is free of sand. They may also lack space and facilities for composting. For this reason, it would be beneficial to cooperate with other municipalities, local waste management companies, and private beach cleaning companies for recycling beach wrack through composting.

Case study 4: Assessment of beach wrack applicability for dune restoration measures (Wrack4coast)



Authors: Gorbunova J., Domnin D., Domnina A., Chubarenko B., Rylkow O., Mayorova Iu.

Case study partner: Atlantic Branch of P.P.Shirshov Institute of Oceanology of Russian Academy of Sciences (ABIORAS) in cooperation with National Park "Curonian Spit", Associated Partner (AP)

Location of the case study: Kaliningrad Oblast, Russia

Aim of the case study: To 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 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) using the bach 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.

Staff involved: Julia Gorbunova, Boris Chubarenko, Dmitry Domnin, Anastasia Domnina, Alexey Grave (all ABIORAS), Oleg Rylkow, Iuliia Mayorova (both AP)

4.1 Location and geographical description (D. Domnin)

The Kaliningrad Oblast is the most western, exclave region of the Russian Federation (→ Fig. 4.1). From the west, it is washed by the Baltic Sea, has two inland marine transboundary waterbodies – the Curonian and Vistula Lagoons. The lagoons are separated from the sea by the sandy Curonian and Vistula Spits, respectively. In the south, the Kaliningrad Oblast has a border with Poland, north and east – with Lithuania. The area of the Oblast (together with the lagoons) is 15.1. km². The length of the coastline is 145 km, of which the spits occupy 72 km. The Kaliningrad Oblast suffers from coastal erosion and cliff abrasion (→ Fig. 4.2) due to storm activity. During the winter storms, seashores erode, and during summer lulls, sandy beaches increase. The "hard" shore protection structures are used to protect the Sambia Peninsula shores, and the "light" ones are applied to preserve the sandy spits.

Thus, several sites were identified for the case study of beach wrack in the Kaliningrad Oblast (→ Fig. 4.1): the area on the Curonian Spit where artificial planting using beach wrack–based compost was made; the area on the Vistula Spit to use



Figure 4.1 Location of the case study sites in the Kaliningrad Oblast. 1 – the experimental site for beach wrack use for greenery planting; 2 – the experimental site for beach wrack use for sand accumulation constrictions; 3 – the site for regular beach wrack monitoring and sampling on an unmanaged beach; 4 – the site for regular beach wrack monitoring and sampling on a managed beach; 5 – the site for beach wrack residence time remote monitoring (webcam).



Figure 4.2. Coastal erosion (the western part of the Curonian Spit, Kaliningrad Oblast, Russia, March, 2020), photo: J. Gorbunova.

beach wrack for sand trapping structures; several sections on the northern shore of Sambia Peninsula where observations were made (Filinskaya Bay, beaches in Zelenogradsk and Otradnoe).

4.2. Description of the case study sites (J. Gorbunova)

The experimental implementation of case study 4 (Wrack4coast) was carried out on the two spits of

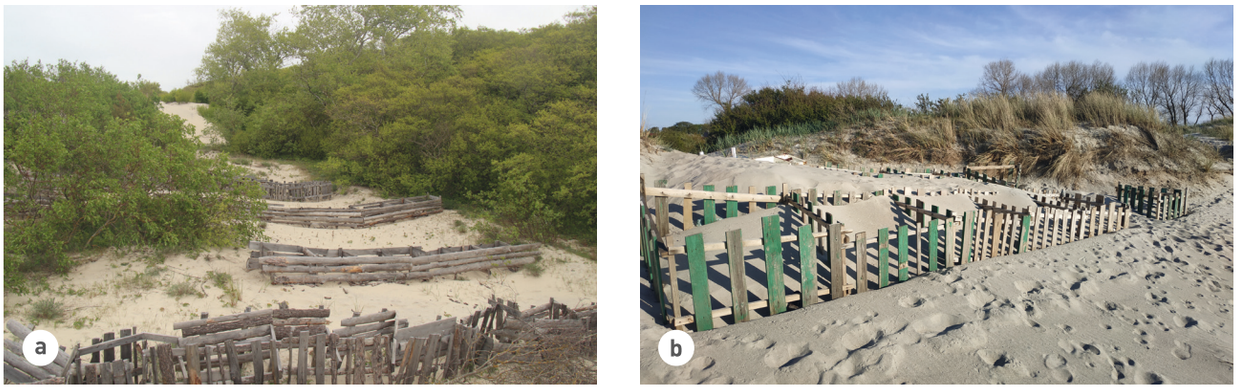


Figure 4.3. Experimental sites for beach wrack use for coast protection measures: (a) for greenery planting, (b) for sand accumulation constrictions, photos: (a) O. Rylkow, (b) B. Chubarenko.

Kaliningrad Oblast. The Experimental site for beach wrack use for greenery planting (→ Fig.4.3) was situated in the western part of the Curonian Spit in the Federal State Budget Institution "National Park "Curonian Spit". The Experimental site for beach wrack use for sand accumulation constrictions (→ Fig.4.3) was situated in the eastern part of the Vistula Spit on the Kosa settlement beach.

Regular beach wrack monitoring and sampling were carried out on the beaches of the northern part of the Sambia Peninsula (→ Fig. 4.4): unmanaged ones – in the Filinskaya Bay and managed ones – on the eastern part of the Zelenogradsk beach. The site for the beach wrack residence time remote monitoring by a webcam was in the western part of the Otradnoye beach (→ Fig. 4.4), and on the northern part of the Sambia Peninsula.

4.3 Beach wrack effect as a natural process (J. Gorbunova)

4.3.1 The problem of beach wrack in the Kaliningrad Oblast, Russia

The problem of beach wrack is present in the Kaliningrad Oblast of Russia, South-Eastern Baltic. From time to time, large amounts of beach wrack appear in various places along its seashore. Apart from some preliminary studies, beach wrack casting's natural conditions were not studied in detail, and beach wrack cast quantities were not estimated yet [Golmanova & Volodina, 2013; Besedina & Nazarova, 2017]. VNIRO Institute scientists studied algae's washouts on the eastern Baltic coast in 1950–1956 [Kireeva, 1960], 1968–1972 [Blinova, 1971; Blinova & Kutyunis, 1973]. However, these studies were confined to Lithuania and Latvia's seashore and focused on commercial species of algae only (*Fucus, Furcellaria*). Questions about conditions and sites of beach wrack release, as well as the estimated beach wrack quantities at the seashores of Kaliningrad Oblast are still open.

4.3.2 Shore surveys and continuous visual observations

A survey of the Baltic Sea seashore within the Kaliningrad Oblast was conducted in March 2019 – August 2020. The beach wrack was recorded (measured, described and geo-referenced using GPS navigation), and sampled at two model sites (managed and unmanaged) monthly (→ Fig. 4.4) and alongshore surveys were carried out seasonally.

Monitoring of the time of residence of the beach wrack was carried out three times per day (November 1 2019 – May 14, 2020, and after August 25 2020), and five times per day (May 15 – August 25 2020) at the selected model site on the Otradnoye beach by using a web camera (→ Fig. 4.4).

4.3.3 The ways of beach wrack transformation on the beach

Beach wrack effect is a natural process in the seashore ecosystems of Kaliningrad Oblast. The further transformation of beach wrack can develop in several ways: flushing back to the sea (the most common), being covered under the layer of sand or small pebbles (also followed by flushing, in most cases), the wind-wave dispersal along the beach (→ Fig. 4.5).

4.3.4 Spatial distribution and amount

It was found out that the distribution of beach wrack was characterized by significant spatial and temporal variability. In general, large amounts of beach wrack were observed on the northern coast of the Sambia Peninsula, contrasting to the western coast, Curonian and Vistula spits. The

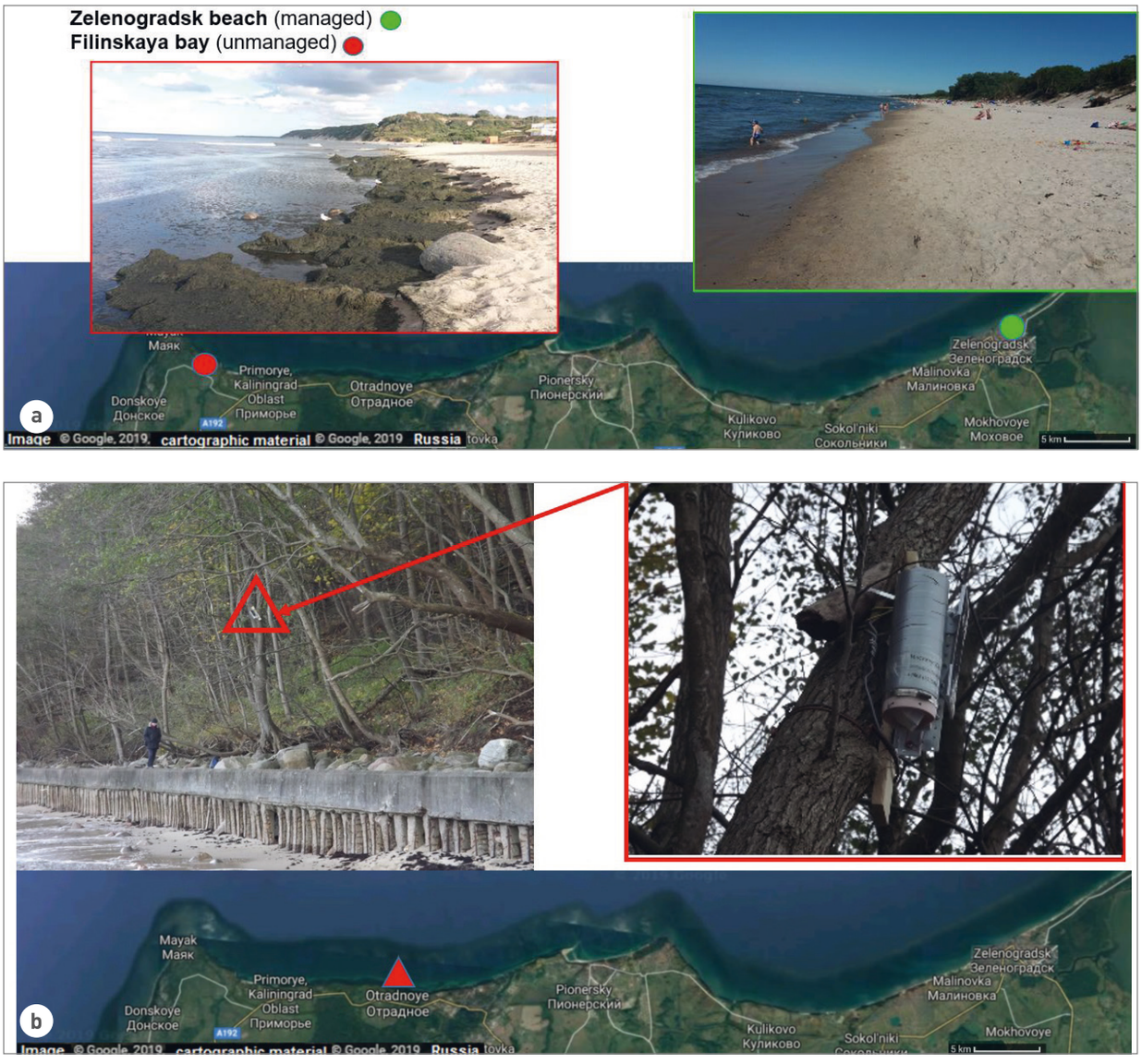


Figure 4.4. Beach wrack regular monitoring sites: (a) an unmanaged beach (Filinskaya Bay and a managed beach (Zelenogradsk), (b) a webcam (Otradnoye beach), photos: (a) J. Gorbunova, (b) A. Grave.

largest accumulations of beach wrack were local and mainly occurred near the coastline protrusions, such as capes (natural) and breakwaters, slipways, groins (human-made).

The most considerable amounts of beach wrack in summer 2019 were recorded in the area of the northern breakwater in Baltiysk; in the Filinskaya Bay (especially in the area of the slip); in the western part of the beach of Pionersky, behind the breakwater of the port; in the area of the Zaostrovie village, behind the Gvardeysky Cape; in the western part of the Otradnoye village beach; and beyond the eastern border of the municipal beach of Zelenogradsk. The most considerable amounts of beach wrack in early spring 2020 were recorded in the Filinskaya Bay area and the Otradnoye beach (→ Fig. 4.6).

4.3.5 Seasonality and composition

The composition and amount of beach wrack result from the see grasses growing disrupted and transported in near-shore waters [Mossbauer et al., 2012]. The seasonal dynamics of algae species in the composition of beach wrack were observed. beach wrack mainly contained *Rhodophyta* algae in early spring, autumn and winter, in contrast to summer, when there were also *Chlorophyta*.

4.3.6 Time of residence

beach wrack residence on the shore varied greatly and was often limited to a few days. During the observation period (November 2019 – May 2020), the residence time ranged from 22 days to less than one day, and on average was 4 days.

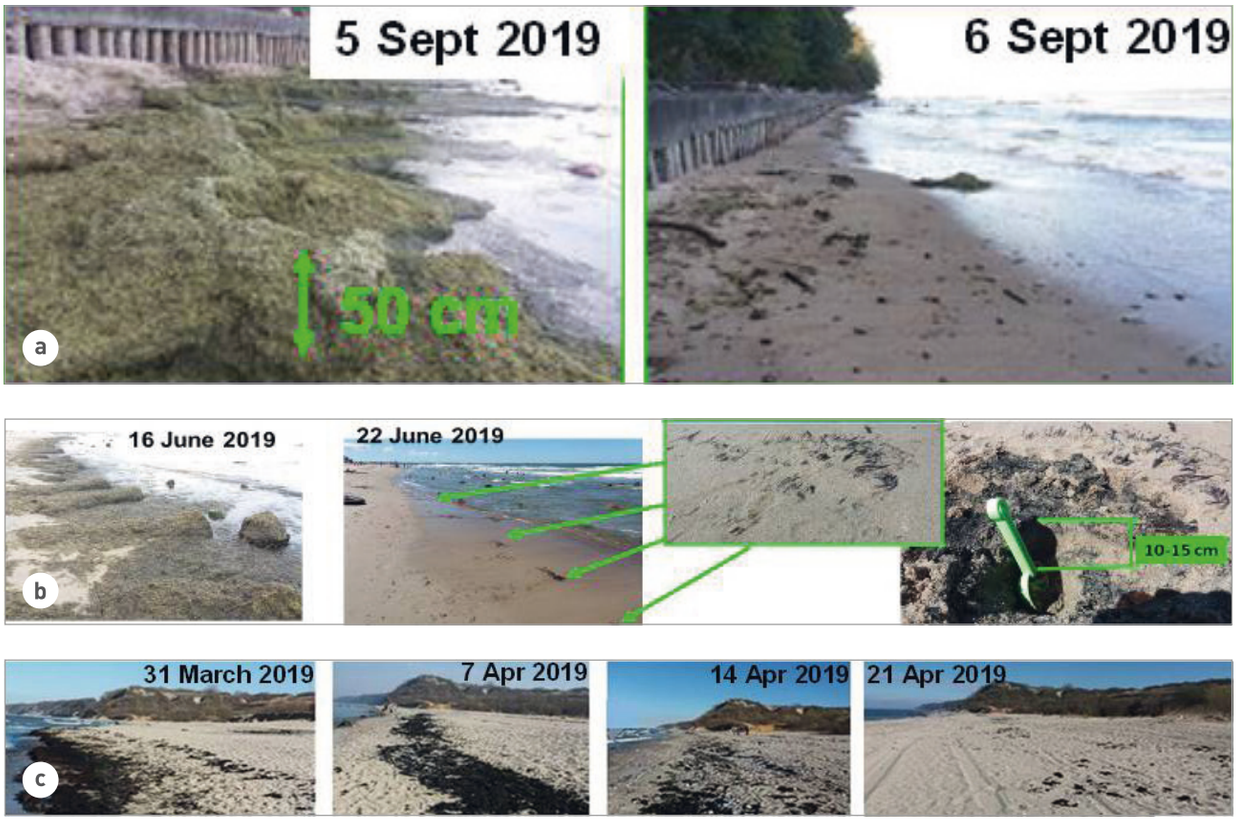


Figure 4.5. Beach wrack can undergo different transformations: flushing back to the sea (a), being covered under a layer of sand or small pebbles (b), the wind-wave dispersal along the beach (c), photos: J. Gorbunova.

The time of beach wrack residence was associated with the strength and direction of the waves, which in their turn depended on the strength and direction of the wind. The beach wrack usually stays on the beach in winds of eastern and southern directions and low wind of western directions. Flushing of the beach wrack was due to intensive winds of northern and western directions wherein the waves flooded the beach and washed away the beach wrack (→ Fig. 4.7).

Wind-wave conditions also define the appearance of the beach wrack. However, the dependence between the appearance of beach wrack and winds of specific directions and forces is less evident than the beach wrack washout from the beach.

The beach wrack's appearance on the Otradnoye beach (the northern coast of the Sambia Peninsula) was most often accompanied by winds of the eastern and southern directions and the western direction, but not very intensive. The dependence of the beach wrack appearance from the east side of the groin on the east wind was quite noticeable. Some days before the beach wrack appearance, there was often a storm happening. The literature describes the dependence of beach wrack on the strength and direction of waves and wind. West stormy wind (southwest, northwest) caused the beach wrack cast on Lithuania's coast [Blinova, 1971]. The beach wrack cast's primary condition is the sequence of two events: the drift of macroalgae to the water's edge and the subsequent rapid decrease in sea level, in which the beach wrack drifted near the shore stays on the beach.

4.3.7 Beach wrack characteristics and conclusions

As the studies have shown, the original wet weight of beach wrack is 450 kg·m-3 on average. The original wet weight of beach wrack varies greatly depending on the content of sand and small pebbles, as well as the humidity of the algae, and can reach 1,072 kg·m-3. The average sand content in the beach wrack is 39 % and can reach 87 %. Little sand content in beach wrack is rare. The situation, when sand was absent in beach wrack, was observed only once.

beach wrack contained xenomaterials, most of which were plastic (→ Fig. 4.8). The xenomaterial inclusions were in 28 % of samples; 99.9 % of them were mesoplastic, and 77 % of those were polyethylene (size 1-50 cm^2). Thus, on average 1 m^3 of



Figure 4.6. Beach wrack stock estimations, as of July 2019 (Curonian Spit, September 2019) (a) and March 2020 (b): 1 – beach wrack layer thickness more than 15 cm; 2 – beach wrack layer thickness less than 15 cm; 3 – beach wrack is absent or in a small amount (coverage with beach wrack is not continuous).

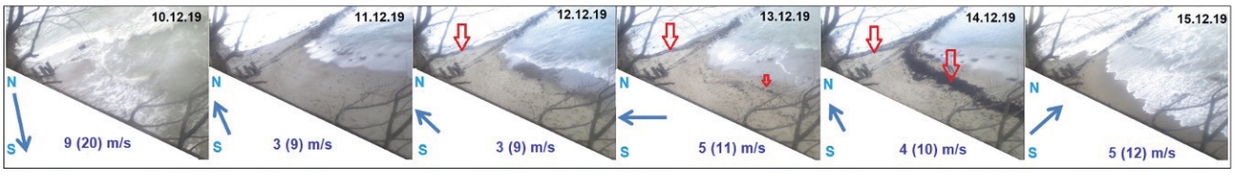


Figure 4.7. A typical example of beach wrack being cast and flushed away, due to the wind conditions (beach of the Otradnoye settlement, northern exposure of the coastline). The measured average wind direction and speed are indicated (wind gusts – in the bracket, the weather station is located at a distance of 5 km, *https://rp5.ru*).

beach wrack contained ~ 130 pieces of xenomaterial inclusions, including ~ 0.06 m² of polyethylene. The estimations show that the industrial use of beach wrack is limited by the spatial and temporal irregularity of its casts in the Kaliningrad Oblast, Russia. However, the need for beach wrack collection and utilization still exists. beach wrack can be used as an additional improver in ongoing shore consolidation activities, namely planting dune greenery, as a source of nutrients.

A possible solution could be to use the webcam observations on the potential seashore with good transport accessibility to coordinate the beach wrack harvesting activities. It is more efficient to harvest beach wrack from new casts, as after being flushing flushed back into to the sea and subsequent subsequently cast again, the beach wrack contains more sand and litter.

4.4 Estimations of areas and volume of the beach wrack cast on the shore at the model site (D. Domnin)

The webcam, temporarily installed in the Otradnoye settlement, was programmed to receive regular images, covering the beach to the west and east of the groin. Images were shot several times a day during daylight hours (at 9, 12, 15 o'clock local time). Additionally, the shooting was done at 6, 18 and 21 o'clock for longer daylight hours. The pictures show the beach and the beach wrack cast onto it (→ Fig. 4.9).

The analysis of the images was carried out in two stages. At first, the information on the beach and beach wrack cast on both sides of the groin was visually estimated, and the data was recorded in the "yes/no" table. Next, only the images with beach wrack were selected, and the areas covered with beach wrack were estimated.

The digitization of the cast boundaries introduced the main error in determining the area of beach wrack in the webcam image. The error was also affected by the beach wrack cast's continuity – the error increases with dispersed spots of the cast. The error value was +/- 10 %.

From November 1, 2019, to May 31, 2020 (213 days), the beach was nearly always in place from both



Figure 4.8. Typical inclusions of mesoplastic in the beach wrack, photos: J. Gorbunova.

sides of the groin. And there was a small asymmetry – the beach was attached for 160 days to the west of the groin, and for 154 days – to the east of it. The beach was absent for 53 and 59 days, respectively (→ Fig. 4.10)

Beach wrack appeared only if there was a beach in place. Situations, when the beach wrack existed, but the beach was absent, were not recorded. In most cases, beach wrack appeared several days after the formation of the beach.

The largest number of days, when the beach wrack casts were on the beach, was recorded in November 2019 (more than 20 days). In December, the number of days decreased to 7, in January and February there were practically no beach wrack, and from March to May 2020, beach wrack reappeared, but less often than during 15 days a month. In fact, for all the months, when beach wrack was present on the beach, there was always more beach wrack to the east of the groin (→ Fig. 4.11).

To estimate the volume and weight of the beach wrack collected from the beach, the beach wrack sampling at the two sites (1.9 m² and 6.5 m²) were made on 07.10.2020. On the site No1, the beach wrack was mostly fresh; 120 litres were collected with a total weight of 91.3 kg. On the site No2, the beach wrack was mostly not fresh, mostly old and



Figure 4.9 The original image obtained from the webcam installed near the Otradnoye sett., the Kaliningrad Oblast (Russia).

partially trampled, previously cast beach wrack (90 %) and a small amount of fresh beach wrack (10 %). 110 litres weighing 119.5 kg were collected from the site No2.

Experimental data shows that the volume of wet beach wrack with sand material gathered from one linear meter of the waterfront from site 1 (fresh beach wrack) and 2 (not fresh beach wrack) was 120 and 110 litres respectively, that gives the mass of 91.3 and 119.5 kg of dry beach wrack with sand. The amount of material gathered from 1 m² of the beach wrack cast from site 1 (fresh beach wrack), and 2 (not fresh beach wrack) were 63.2 and 16.9 litres per m² or 48.1 and 18.4 kg per m². Thus, we may conclude that the specific volume of the fresh beach wrack (after its gathering for transportation) is 3.7 times higher than the one of the not new and caked beach wrack, while the specific mass of the fresh beach wrack is 2.6 times bigger than of the not fresh beach wrack.

4.5 Beach wrack for the planting of greenery, Curonian Spit (J. Gorbunova, O. Rylkow, Iu. Mayorova)

The implementation of case study 4 was carried out in the National Park "Curonian Spit" in collaboration with the Institute of Oceanology RAS.

4.5.1 Historical and environmental aspects

Curonian Spit (UNESCO World Heritage Site) is a sand-dune spit that separates the Curonian Lagoon from the Baltic Sea. The destruction of the foredune wall leads to the threat of the flooding the forest located on the Spit [Karmanov et al., 2018]. Planting of greenery is a measure used on the Curonian Spit since long ago. The foredune of the Curonian Spit is mostly a human-made construction mounted in

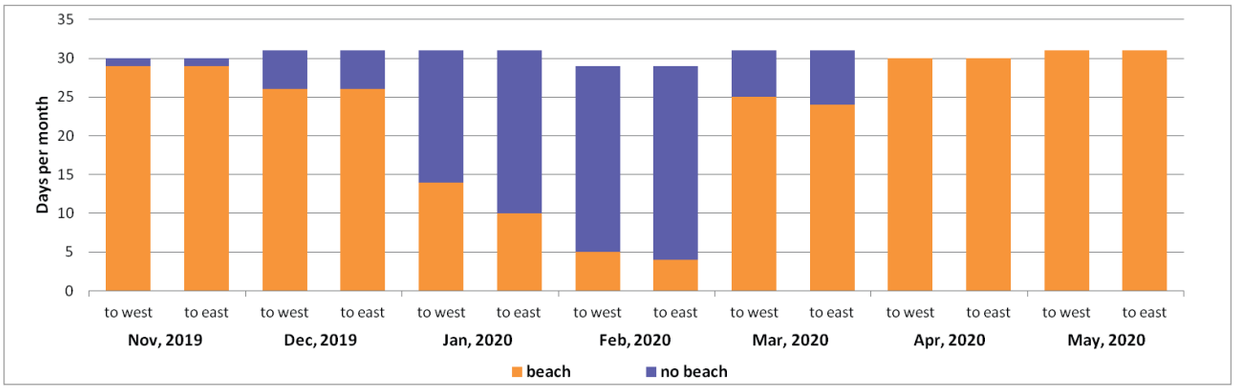


Figure 4.10. Monthly variations of beach presence to the west and east from the groin from November 1, 2019, to May 31, 2020.

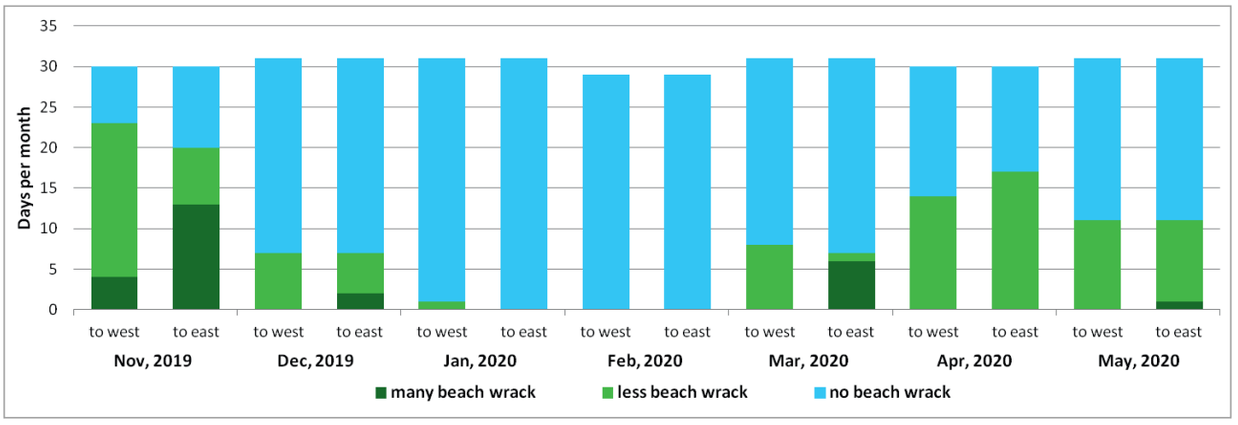


Figure 4.11. Monthly variations of the beach wrack presence to the west and east from the groin in the period from November 1, 2019, to May 31, 2020

XIX with successive use of wooden structures and greenery [Curonian..., 2008]. By analogy with the historical use of algae to fertilize soil [McHugh, 2003], greenery planting could be significantly more effective with beach wrack as a source of nutrients. It should be similar to a natural process. Algae thrown ashore are a component of fertilizer for dune vegetation in the process of coastal dune formation [Walter, 1975]. With this method, xenobiotic substances will not be brought into the environment, since algae from beach wrack are an inherent part of the coastal ecosystems.

4.5.2. Substantiation of the methodology and selection of plant species

Agrarian and climatic conditions on the open sandy surface of the dune wall are harsh. It is practical to use fertilizers that stimulate seedlings' growth and survival to increase vegetation plantings' survival rate. That is why the use of beach wrack as a natural fertilizer looks promising.

Organic fertilizer from beach wrack was obtained by composting with methods similar to those used for planting green plants [Druzhinina et al., 2016; Tarkhanova & Lobkova, 2015; Vasiliev, 2015]. For that, a wooden container was used. The composted mass of beach wrack was stirred to aerate it and prevent putrefactive processes. The consistency of organic matter determined the duration of composting.

Studies of the beach wrack compost's effectiveness were done by standard methods accounting for the morphological parameters and survival rate of seedlings. The planting of greenery was carried out at the experimental and representative sites to identify the differences' significance.

There are harsh habitat conditions in the dune wall – strong winds, unstable sand soils, periodical salinization by sea spatters. Only some species of plants with adaptive properties can exist under such conditions. The plant has to be resistant to sanding, exposure of roots, and recreational loads as well.

Berberis vulgaris was chosen for planting as it is tolerant of low soil humidity and low temperature. This specie of barberry is characterized by an early start and late completion of the growing season, and it reaches a height of 1.5-2 m under favourable

ACTIVITY	PERIOD
Supplementary scientific work – methodology and data analyses.	January 2019 – December 2020
Preparation of seed material – harvesting and planting of seeds.	October 2018
Cultivation of (watering, weeding, loosening) the planted seedlings.	April – September 2019
Construction of a compost container.	September 2019
Beach wrack harvesting and transportation.	October, November 2019
Beach wrack composting with mixing (aeration) and monitoring of the environmental conditions (temperature).	November 2019 – May 2020
Planting and cultivation of the yearlings at the case study sites.	May – September 2020
Inventory of the yearlings (survival and morphological parameters).	June, September 2020

Table 4.2. Schedule of experimental activities

conditions. Resistance to this plant's anthropogenic impact is ensured by thorns on the branches and a robust root system, horizontally diverging below summer drying horizon.

4.5.3. Schedule of experimental activities

The schedule of the main stages of the experiment is presented in → Table 4.2.





4.5.4 Beach wrack harvesting and transportation

In the Kaliningrad Oblast, beach wrack casts are characterized by their spatial and temporal irregularity (see Chapter 4.3.4 and 4.3.5), which causes significant difficulty for their harvesting. To solve this problem, a "quick response" method was used based on seaside monitoring results. A small beach wrack cast occurred in October 2019 on the Curonian Spit close to the case study site (→ Fig. 4.12 a,b). It was convenient and cost-effective in terms of transportation costs. However, the amount of beach wrack harvested on the Curonian Spit was not enough for the experiment's needs. Beach wrack casts are very rare on the Curonian Spit. Therefore,

Figure 4.12. Beach wrack harvesting by hand (a) on the Curonian Spit (b) and in the Filinskaya Bay (c). Photos: (a), (b) O. Rylkow, (c) J. Gorbunova.



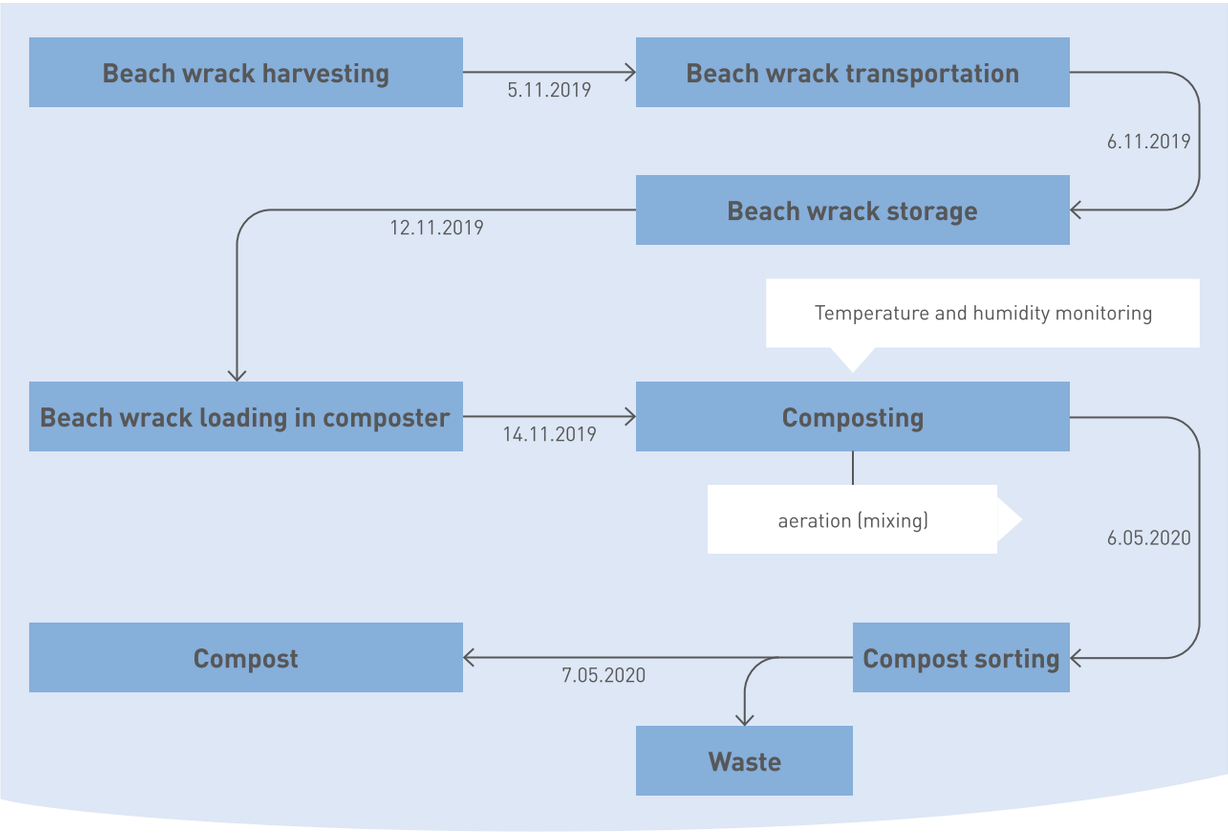


Figure 4.13 The beach wrack composting scheme.

the required amount of beach wrack was harvested in the Filinskaya Bay (→ Fig. 4.12 c) located at 50 km from the Curonian Spit, in November 2019. In this part of the seashore, large amounts of beach wrack often appear (see Chapter 4.3.4), and there is good transport accessibility to this seaside area.

Beach wrack was harvested by hand (→ Fig. 4.12 a). Separation of impurities (sand, land vegetation, garbage, etc.) was not done. There was very little garbage in the harvested beach wrack. A total of 500 kg of beach wrack were harvested, and about 90 % of that amount was from the Filinskaya Bay. The algae's dominant species were *Furacellaria lumbricalis* (Filinskaya Bay) and Cladophora sp. (Curonian Spit).

4.5.5 Beach wrack composting

The scheme used for beach wrack composting is shown in Fig. 4.13. The experimental composting site was a square wooden container (2x2x1 m) placed on low brackets to improve aeration. The container sides were lined around the perimeter with packages of hay to prevent freezing in winter. The compost container was constructed outdoors on sandy soil without any special drainage.

Beach wrack was placed in the compost container's central part without tamping and covered with hay (→ Fig. 4.14). Composting process was carried out from December 2019 to May 2020. No additional irrigation was done. The surrounding temperature was 0°C– +7 °C in winter. Aeration of the compost mass was carried out by stirring it in December 2019 (→ Fig. 4.14). A gradual temperature decrease of compost mass was observed from 29 °C to + 10–12 °C in 8 weeks.

As a result, in early May 2020, the compost was loose, crumbly, with a slight ammonia smell, and dark in colour. It contained a significant amount of beach sand and no initial algae fragments.

4.5.6 Planting material

The planting material was the yearlings of *Berberis vulgaris* (→ Fig. 4.15). Seeds were harvested from wild bushes on the Curonian Spit. They were planted in October 2018. Irrigation, weeding and loosening were done during the cultivation in April–September 2019. In May 2020, The size of yearlings was 18–25 cm.

4.5.7 Case study sites description

Case study sites were placed in the dune wall section at the 15-kilometre mark on the Curonian Spit.

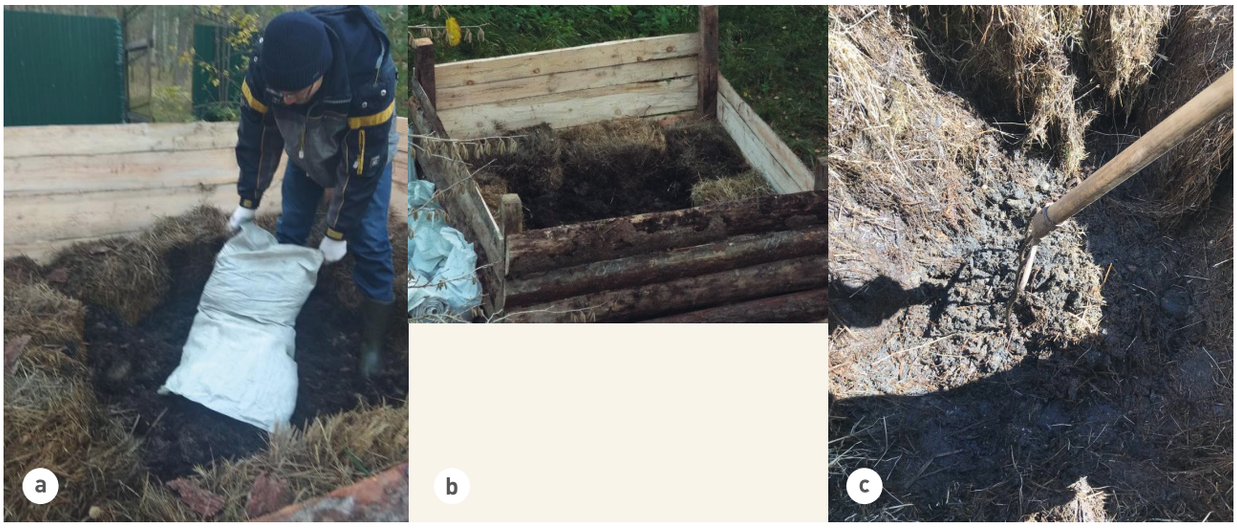


Figure 4.14. Beach wrack composting: (a) storage in the composting container (b) and aeration/stirring of the beach wrack compost mass (c), photos: (a), (b) O. Rylkow, (c) Iu. Mayorova.



Figure 4.15. Cultivation of the planting material: (a) planting of seeds and (b) barberry seedlings in May 2019, photos: O. Rylkow.

The mechanical consolidation of sand in this area was done by wooden cells (0.7 m high) in 2017–2018 (→ Fig. 4.16). The downwind slope of the dune wall was chosen for the case study. The size of the area was 5x10 m. The slope's local relief was not flat, the slope at the focus area was 15-20° and faced to Southeast. The vegetation was absent with rare exceptions of some herbs (*Corynephorus canescens, Carex arenaria, Lathyrus maritimus*).

4.5.8 Planting and cultivation

Planting was carried out in May 2020, after the seedlings' spring vegetation had started (→ Fig. 4.17). Greenery was planted at two sites: experimental and verification ones. Pits were made with a shovel (a hand drill). Seedlings were irrigated after planting. Beach wrack compost was applied at a depth of 20-30 cm at the experimental site only. Compost mass was added (under the roots) when planting [Rodin & Rodin, 2010].

4.5.9 Effectiveness of the experimental method

A photo testing method was used for the quality assessment of the beach wrack compost. Seedlings were planted at two sites: experimental and verification ones. Beach wrack compost was applied at the experimental site only. The cultivation of plants at the experimental and verification sites was done under identical conditions. The morphological parameters of the plants (length of the aboveground part), as well as the seedlings' survival rate, were determined at the end of the growing season in September 2020 (→ Fig. 4.18).

The following results were obtained: 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.

4.5.10 Business benefit analysis

A cost calculation of planting the greenery with and without compost was made. The following costs were

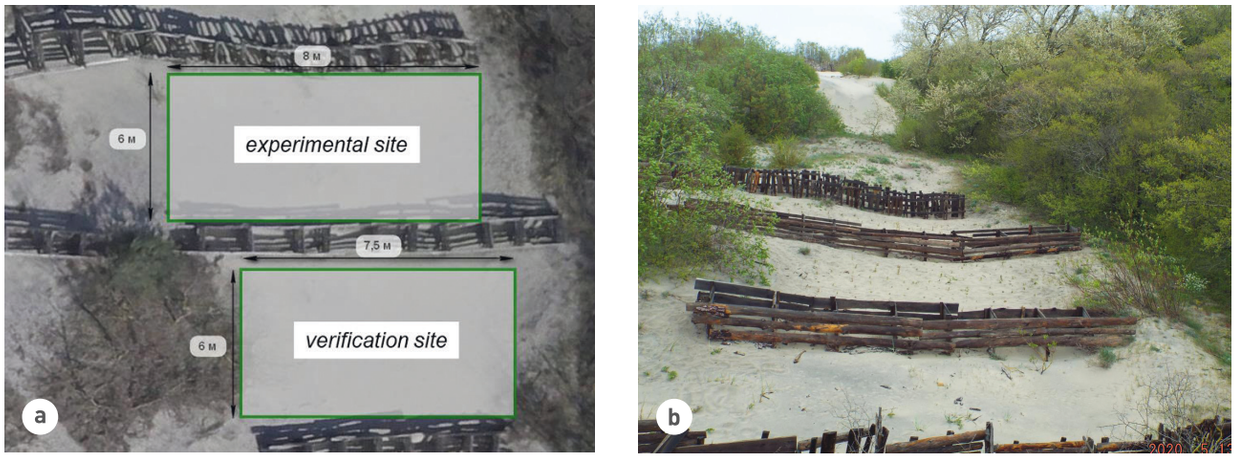


Figure 4.16. Case study sites for the greenery: (a) experimental and verification sites; (b) mechanical consolidation of sand by wooden cells, photos: O. Rylkow.



Figure 4.17. Planting (a) and cultivation (b) of *Berberis vulgaris* yearlings (c). Photos: (a), (c) O. Rylkow, (b) Iu. Mayorova.

taken into account: cultivation of planting material (seedlings of *Berberis vulgaris*); planting and cultivating *Berberis vulgaris* yearlings (within one vegetation season); beach wrack composting technology. In total, the costs per 100 plants 35 person-hours in the case of beach wrack compost application, and 11 person-hours without it.

Beach wrack monitoring costs were not taken into account in the case of growing greenery with beach wrack compost. This monitoring was carried out simultaneously as a part of the implementation of CONTRA Work Package 3 (see Chapter 4.3.2). The cost of such monitoring for beach wrack harvesting purpose only is relatively high. A cheap solution would be to use a webcam on a potentially profitable seashore. The results of Work Package 3 will allow us to choose an area suitable for that purpose on the Kaliningrad Oblast seacoast. The webcam technology was developed as part of Work Package 3 and can be recommended for further use to coordinate the beach wrack harvesting activities under the conditions of the Kaliningrad Oblast. After installing the equipment, the cost of its operation is 2 person-hours a day per month and 100 Kb of Internet traffic per month, in the case that the source of energy for the webcam is solar radiation.

In general, the growing of seedlings with compost costs about 3.5 times more than without compost in the first year.

4.5.11 Conclusions

As shown by the results of the Wrack4coast experiment within the CONTRA project, beach wrack could be used for planting greenery to stabilize the dune wall. The 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 it, while the survival rate of seedlings grown with and without beach wrack compost was practically the same after one vegetation season. At the same time, undoubtedly the viability of plants grown with compost is much higher than without it. Therefore, the precise calculations of beach wrack compost use's long-term effect can only be assessed after a few years, when the tests in winter frosts and summer droughts are passed, which is outside the project timeline. At present, the main conclusion can be made that the use of beach wrack for dune greenery is effective.

High sand content in beach wrack is not a problem when used in dunes. beach wrack contains xeno-material components, most of which are plastic.



Figure 4.18. Results of the planting of the seedlings at (a) experimental and (b) verification sites in September 2020 (one vegetation season cultivation). Photos: J. Gorbunova.

Biodegradable plastics possibly are decomposed by composting, however, this needs detailed research. Macroplastic and part of mesoplastic can be picked out during the beach wrack and compost sorting at the beginning and the end of the technological process. The most significant difficulty is microplastic, which cannot be removed by simple methods. Moreover, it can appear as a result of the crushing of macroplastic and mesoplastic. An attempt to reduce the problem is to harvest the beach wrack from a new cast.

Use of beach wrack for coastal protection greenery is close to a natural process – algae cast ashore are an essential component as a fertilizer for dune vegetation in coastal dunes formation. The thickets of vegetation at the back of the beach accumulate some beach wrack amount for effective greenery growth. However, unlike in a natural process, more beach wrack needs to make the beach wrack-based compost preliminary. Otherwise, processes of anaerobic decomposition of organic matter may occur, which would negatively affect the plants. The technology for beach wrack compost processing and its application for dune greenery were developed within the Wrack4coast CONTRA project.

The irregular appearance of beach wrack in the Kaliningrad Oblast limits its industrial use. Its collection and utilization are also a problem. A possible solution might be to use beach wrack as an additional improver in ongoing shore consolidation activities. Use of beach wrack is preferable compared to other materials, as it is not an extrinsic agent for the coastal ecosystems. Beach wrack may be involved in the soft engineering techniques that work well with nature to manage the coastline. Thus, it is possible to combine the solution of two current problems of the Baltic Sea coast in the Kaliningrad Oblast – coastal abrasion (due to dune wall consolidation) and pollution by beach wrack.

4.5.12 Alternative use, the example from the Vistula Spit (B. Chubarenko)

Another possible application of beach wrack is to use it as a filler in the first layer of wooden cells used to restore the dunes and wind-blown gaps in them. Construction of these wooden cells is a traditional way of arranging the sand accumulation before and after the foredune wall. Wood wooden constructions for sand accumulation are usable, but are not always effectively filled with sand, especially in the initial period, just after their construction (→ Fig. 4.19).

In contrast to other applications [Macreadie et al., 2017], this possible solution of using beach wrack for coastal protection purposes has not yet been tested. Beach wrack may be involved in soft engineering techniques to manage the coastline. Still, economic profit depends on the amount of available beach wrack and the possibility of collecting it from sandy shores and stony areas.

The experiment was organized at the Vistula Spit shore, where several wooden cells were constructed, and some of them were preliminarily filled with beach wrack (30 pails per each). It shows (→ Fig. 4.20) that filling the cells with beach wrack didn't influence on grass growing in the cell. The filling of the cell with beach wrack helped only at the initial stage. After several windy periods, all cells were filled with sand nearly equally irrespective of whether some of them had been partly filled with beach wrack at the beginning or not.

After the vegetation period, it became clear that beach wrack itself is not a suitable substrate for grass growing. The grass grew only in the cells, which were partly filled with ordinary hummus together with beach wrack. The grass didn't grow in the cells filled with beach wrack only.

The extent of filling the cells with sand mostly depends on the structure's configuration – a single cell doesn't work. In contrast, a two-row cell construction showed the best results, The sand was



Figure 4.19. Beach wrack could be the best initial filler for wooden cells (a) used for sand accumulation, (b) in the wind-induced blowing gaps in the foredune wall, photos: B. Chubarenko.

well stored in between two rows of cells, the second (back) row of the cell was filled, and the sand accumulated behind the back row. The cells in the front row were always filled with sand by 50-70 %.

4.6 Management, administrative and legal obstacles (B. Chubarenko)

The Kaliningrad Oblast shoreline's length is about 145 km, and only a few kilometres are managed as public beaches. These are city public beaches in Yantarny (about 1 km on the Sambia Peninsula's eastern shore) and Zelenogradsk (about 1 km on the northern shore).

Practically, only in Yantarny, there is a regular beach wrack collection experience, namely, during the every year preparation of the beach to the touristic season. The collected material is not processed; it was transported to the city landfill, stored separately without being mixed with other wastes.

In Zelenogradsk the need to collect beach wrack from the beach has emerged a couple of times only. The reason is that, due to hydrodynamic conditions and bottom sediment structure, the beach wrack is washed ashore very rarely in this area. When it happened some time ago, the city cleaning service collected the beach wrack by hand and transported it in a tractor-trailer to the local landfill, where it was stored separately from other waste. In both locations, Yantarny and Zelenogradsk some amount of the collected beach wrack was taken by gardeners from the landfill.

Collection of beach wrack is not a regular operation in the Kaliningrad Oblast. Most of the beach wrack cast to the beaches are either buried under the sand or washed back into the sea.

Preliminary analysis and discussions with experts and practitioners showed that beach wrack is not a subject of any legislative or administrative document related to Russia's environmental conservation. However, local authorities' soft measures (wooden cages for dune stabilization) could be practised within their regular coastal management responsibilities.

4.7 Conclusions and practical recommendations

Only a few kilometres of the 145 km of the Kaliningrad Oblast shoreline's length are managed as public beaches. These are city beaches in Yantarny (about 1 km on the Sambia Peninsula's eastern shore) and Zelenogradsk (about 0.5 km on the northern shore).

The regular beach wrack collection experience (the every year preparation of the beach to the touristic season) is only in Yantarny, where the collected material is not processed but transported to the city landfill, stored separately without being mixed with other wastes.

In fact, in Yantarny and Zelenogradsk, the need to collect beach wrack from the beach appeared a couple of times only. Due to hydrodynamic conditions and type of the bottom sediments, the beach wrack has washed ashore very rarely in this area.

The extensive coastal monitoring showed that the industrial use of beach wrack is limited by the spatial and temporal irregularity of its appearance on the beaches of the Kaliningrad Oblast.

A possible solution to beach wrack collection and utilization in Kaliningrad Oblast could be the use of beach wrack for compost during the activities on the greenery the coastal dunes, which is similar to a natural process. In that way, beach wrack could be involved in soft engineering techniques to manage the coastline.

The following practical recommendations were formulated:

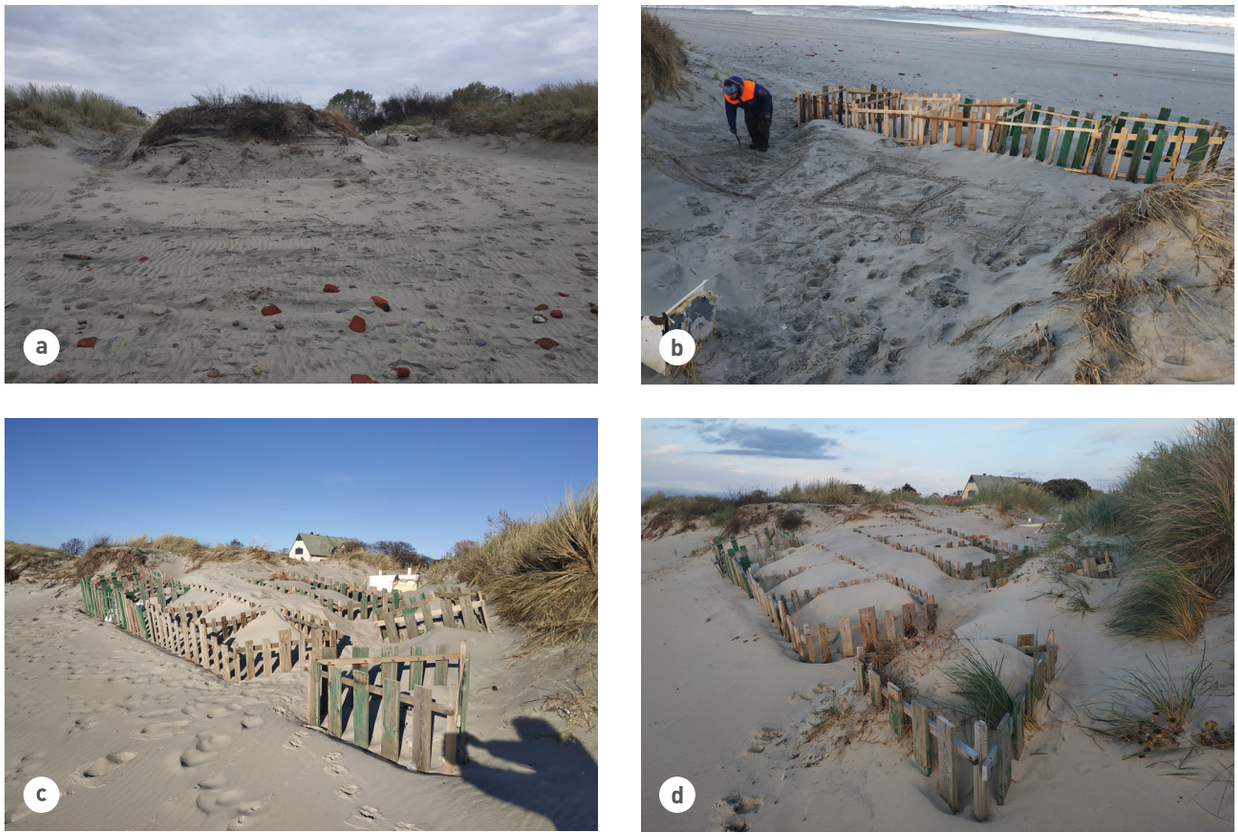


Figure 4.20. Experiment with wooden cells on the shore of the Vistula Spit: (a) the selected site (the right passage through the foredune), (b) construction process, December 2019, (c) after the wintertime, March 2020, (d) after the summer, with some grass already grown in triangular cells, which were preliminarily filled with beach wrack, October 2020. Photos: B. Chubarenko.

Beach wrack harvesting:

- Choose potentially profitable seashore areas for beach wrack harvesting, where beach wrack is cast frequently, and transport accessibility is good.
- Use webcam observations on the seashore potentially profitable for beach wrack cast to coordinate the beach wrack harvesting activities (relevant for the Kaliningrad Oblast and other areas with poor beach wrack residence time conditions).
- Attempt to harvest beach wrack from a new cast, as its flushing back into the sea usually results in the subsequent casts containing more litter.
- Beach wrack processing for dune greenery purposes:
- Before application beach wrack should be composted for 4-6 months.
- Beach wrack composting is carried out outdoors in wooden containers insulated with hay (low costs).
- The compost mass should be stirred 3 times per preparation period for aeration.

Selection of plant species for the dune greenery

- The plants have to be tolerant of a wide range of temperature, dryness, sanding, exposure of roots and recreational loads and come from the local flora species. In the experiment, Berberis vulgaris showed a good result.

Beach wrack compost application for the dune greenery:

- Yearlings with a stem length of more than 10–15 cm should be used for planting.
- The amount of compost applied should depend on the plant's needs for 1–2 years. In the case of *Berberis vulgaris* yearlings were 0.6–0.9 l of the compost per seedling.
- Compost should be applied to the roots of seedlings at a depth of 20–30 cm when planting.

Acknowledgement: The infrastructures of the Atlantic Branch of P.P.Shirshov Institute of Oceanology of Russian Academy of Sciences (supported by theme No 0128-2021-0012 of the State Assignment) and the National Park "Curonian Spit" were used.

Case study 5: The Baltic beach wrack thermal recovery and relevant analytical performances (ALREA)



Authors: Katrantsiotis Ch., Sachpazidou V., Ibrahim A., Bisters V., Burlakovs J., Hogland W.

Case study partner: Linnaeus University

Location of the case study: Kalmar, Sweden

Aim of the case study: Preliminary analysis of the possibilities to use beach wrack biomass as a feedstock for the production of soil amendment throughout thermal gasification.

Test/research done: Gasification and pyrolysis characterization during thermal conversion of beach wrack biomass at the gasification plant Renteh company (Vienibas gave 87E, Riga LV-1004).

Staff involved: William Hogland, Varvara Sachpazidou, Christos Katrantsiotis, Asim Ibrahim (all – Linnaeus University), Valdis Bisters (Renteh, Latvia), Juris Burlakovs (Geo-IT, Latvia)

5.1 Introduction

Beach wrack is an organic material consisting of old sea-grass biomass, various other marine organisms, as well as litter that accumulate on beaches due to the action of waves, tides, and aperiodic water level fluctuations [Suursaar et al., 2014, Macreadie et al., 2017]. Despite the natural origin of this material and its significant ecological role, beach wrack becomes a social amenity and/or environmental issue, if accumulated in excessive amounts [Kirkman and Kendrick 1997, McGwynne et al. 1988, Dugan et al., 2003, Orr et al., 2005, Nordstrom et al., 2011, Macreadie et al., 2017]. Anthropogenic pressures, such as shoreline reconfiguration, eutrophication, and climate change stimulate the accumulation of wrack onshore and makes the beach wrack problems worse [Macreadie et al., 2011, 2017; Risen et al., 2017]. Moreover, marine eutrophication and climate change do not only affect the accumulation of beach wrack but also the products of its aerobic decomposition. It is estimated that the annual global carbon flux from seagrass wrack to the atmosphere ranges from 1.31 to 19.04 Tg C yr-1 [Liu et al. 2019]. Besides, the material accumulated on the seashore decomposes quickly, accompanied by a troublesome odour that keeps tourists away [Kupczyk et al., 2019]. It is therefore both an ecological problem for the eutrophicated reservoirs and the social one associated with nuisance for





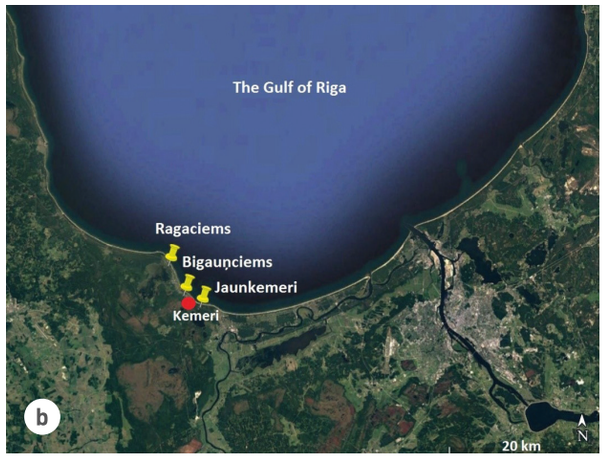


Figure 5.1. Location of sampling sites in Öland (a), Latvia Bay (b) and west coast of Latvia (c) (June 2019)

inhabitants and tourists visiting seaside resorts [Kupczyk et al., 2019].

The aim is to investigate the possibilities of using beach wrack collected on the Island of Öland (Sweden) and in the Gulf of Riga (Latvia) as a feedstock for the production of soil amendment: biochar and gasification syngas as energy recovery of the waste material. This study will contribute to a circular economy and bio waste reduction through recycling /processing of the blue biomass waste. Methods of harvesting will focus on local implementation and keeping quality of the coastal sub-littoral area and beach for tourism. Efficiency analysis (+cost-effectiveness and minimum environmental impact) of choosing beach wrack as for bio covers, soil amendments or biogas will be applied including pilot tests in a reactor with different composition of mixed food waste and algae for anaerobic digestion process. Besides, proportions of beach wrack will be mixed with food residuals and household organic waste to get the most efficient biogas production. The business model will also include the use of algae in agriculture for local farmers and non-governmental organizations (NGOs) and energy sectors (targeted at biogas company).

5.2 Location and geographical description

Samples of beach wrack were collected from sandy beaches of Stenåsa, South-Eastern Öland and Vikegård: North-Eastern Öland, in June 2019 (→ Fig. 5.1a). Öland is a c. 140 km long island in the southern Baltic Sea, near mainland Sweden. The samples were analyzed for calorific values as well as ultimate and approximate composition analysis.

On the South Baltic coast, wrack material was collected from sandy beaches in the Gulf of Riga (Jaunkemeri, Bigauņciems, Ragaciems) and the West coast of Latvia (Liepaja) (→ Fig. 5.1 b,c). The Gulf of Riga has a surface area of 17 913 km^2, a volume of 406 km^3, a maximum depth of 52 m, and an average depth of 23 m [Suursaar et al., 2014]. The largest sample for gasification tests was collected at the Jaunkemeri beach. Termogravitometry and ultimate analysis was made for the collected beach wrack. For anaerobic digestion, three seaweed types were collected in Kemeri (Gulf of Riga): brown, red, and green algae.

5.3 Description of beach wrack effect as a natural process, local peculiarities and characteristics

Beach wrack offers many ecosystem services and a link between the marine and terrestrial environments. It provides habitat (food, nesting, and shelter) to important animal communities including invertebrates and shorebirds that inhabit shorelines and contributes to the coastal and marine food web systems though supplying essential nutrients, as the organic material decomposes and breaks down [Kirkman and Kendrick, 1997, Dugan et al., 2003, Orr et al., 2005, Nordstrom et al., 2011]. Beach wrack supports microbes and other smaller organisms utilised by plants and fish including important

commercial fishery species [Kupczyk et al., 2019]. Beach-cast seagrass accumulations are typically long-lived, taking as many as 3–5 years to fully decompose into detrital matter attributed to their cellulose refibre with characteristics that inhibit the breakdown of the vegetative matter [El-Gamal and El-Kader, 2019]. Thus, beach wrack contributes to the protection of the shoreline and the coastal dunes by providing a physical barrier that dissipates the wave energy, reducing their impact force on the shore [Macreadie et al., 2017, Kupczyk et al., 2019]. Furthermore, beach-cast seagrass wrack enhances the formation and stabilization of coastal dunes and beaches, due to the fibrous composition of seagrass, acting as a trap that binds drifting sands and reduces the erosional process in winter [PIRSA 2014, Kupczyk et al., 2019].

The process of detachment, transport, and accumulation of beach wrack depends on a variety of hydrodynamics and topographical factors [Suursaar et al., 2014]. The material may originate from the nearby areas but can also be carried as algal mats from distant locations, as winds and currents can move the masses towards the shore accumulating huge drift walls [Vahteri et al., 2000]. The beach morphology also determines the morphology of wrack depositions, with the latter being rather patchy in a curved or indented coastline [Orr et al., 2005]. Buoyancy characteristics of the wrack are another factor, as different macrophyte species can be cast ashore more easily than others [Suursaar et al., 2014]. Throughout a year, beach wrack decays and becomes detritus with some species decomposing faster than others. Dry-wrack particles on the shore can become more buoyant and can be moved back to sea during high water events [Suursaar et al., 2014].

The distribution of species as well as the total biomass of the communities has a strong regional pattern related to different ecological conditions [Martin, 1999]. In the Baltic Sea, more than 500 species of macroalgae, aquatic vascular plants, charophytes, and bryophytes have been recorded [HELCOM, 2012, Suursaar et al., 2014]. The number of marine species decreases with the salinity gradient, and the Gulf of Riga has one of the lowest macro vegetation diversity. Forty-three species of macroalgae have been identified in this area [Martin, 1999]. Fucus vesiculosus L. is one of the most common Brown algae in the Gulf of Riga and on the rocky bottoms of the Baltic Sea coastal areas where it forms dense colonies [Torn et al., 2006, Balina et al., 2016]. Other frequent species in the Gulf of Riga are filamentous algae such as Ceramium tenuicorne (Kützing) Waern, Polysiphonia fucoides (Hudson) Greville, Pilayella littoralis (Linnaeus) Kjellman as well as Battersia Arctica (Harvey) Draisma, Prud'homme & H. Kawai [Martin 1999, Suursaar et al., 2014]. In Southern Sweden and Öland, the most common species are Polysiphonia fucoides (Huds.) Grev., and Furcellaria lumbricalis (Huds.) Lamou, as well as sparse Fucus vesiculosus L. and Fucus serratus L. stands (Malm, unpubl.) [Malm et al., 2004].

5.4 Why beach wrack is a problem?

The brackish-water Gulf of Riga is considered one of the most eutrophic basins in the Baltic Sea [Suursaar et al., 2014]. One apparent consequence of eutrophication is an increased production of drifting, filamentous algae, dominated by a few out of several co-occurring opportunistic species [Malm et al., 2004 and references therein]. The nutrients released from decomposing beach wracks can further exacerbate the eutrophication problem (Lastra et al., 2008). The decomposition of beach wrack is often perceived as a kind of "pollution", which promotes insects and bacteria causing a troublesome odour and thus reducing the tourist attractiveness of the seaside resorts and the recreational value of beaches [Kupczyk et al., 2019]. Its removal can therefore be an important management task. Noticeable is that the amount of washed-out algae is not monitored in Latvia [Balina et al., 2017].

The conversion of beach-wrack to biochar could be a viable environmental solution that can provide a value-driven model to sequester and recycle nutrients [Ross et al., 2008; Bird et al., 2011]. Previous studies have shown that "microalgae biochar can provide direct nutrient benefits to soils and stimulate crop productivity and will be useful for the application on acidic soils" [Bird et al., 2011]. Biochar has the potential for an even greater impact on climate through its enhancement of the infertile soil productivity and its effects on soil GHG fluxes than bioenergy, in which CO_2 fixed in the biomass by photosynthesis is returned to the atmosphere quickly as fossil carbon emissions are offset [Woolf et al., 2010].

5.5 Technology tested (Methods and Results)

5.5.1 Beach wrack analysis

The calorific value of the sample from Stenåsa was analysed by incineration in a bomb calorific meter, according to the standard method LVS EN ISO

18125:2017. The ultimate analysis was made according to the methods: LVS EN ISO 16994:2016 (for Cl, S) and ISO 16948:2015 (for C, H, N), the content of O2 was calculated. Proximate composition was estimated using the express method described by Agrawal (1988), the same results are used as thermogravimetry (TG) data (see 5.5.6). For the content of metals and phosphorous, around 250 mg of samples were transferred to Teflon capsules, 9 mL of concentrated HNO3 and 1 mL of 30 % H2O2 were applied to each sample, the capsules were sealed and samples were digested in a microwave oven (Milestone Ethos Easy) at 200 ˚C and 49 bar pressure for 15 minutes. Metal concentrations were analyzed using ICP-OES (Thermo Scientific iCAP 7000 series).

5.5.2 Gasification tests

Gasification is a chemical process that converts carbonaceous material such as biomass and coal into gaseous fuel or chemical feedstock. This gaseous fuel is known as producer gas or syngas which contains CO_2, H_2, CO, H_2O, CH_4 and N_2 compounds. Air gasification has been applied in the beach wrack gasification process. Surplus char which is formed from the pyrolysis process is heated by supplying a limited amount of air in the gasifier. The temperature of the reactor is reliable on the feedstock feed rate and airflow rate. Higher tar and lower gas are produced by supplying low inlet air. Lower heating gas (3–7 MJ/Nm³) is produced which is appropriate syngas applications either for power production or heat recovery in boilers. Drying, pyrolysis, gasification, and oxidation are the four main zones in the gasifier depending upon the relative movement of the gasifying agent and feedstock. Different temperatures and different reactions occurred in different zones. Each zone is relying upon feedstock, gasifying agent, temperature, particle size, moisture content, and chemical composition.

Drying Zone

It receives energy from the other zones through heat transfer to reduce moisture content by up to 5 %. The drying process occurred at 100°C -150°C. A chemical reaction is not taking place in this zone.

Pyrolysis Zone

It is known as the DE volatilization zone, and the process occurred in this zone at 150°C-700°C. DE volatilization of feedstock is occurred due to the heat transfer from a reduction zone. Higher temperature difference occurred due to hot gases and cold feedstock. The thermal and physical properties of biomass feedstock are changed due to the higher temperature. Gases, liquid (oil and tars), and char are the products of this zone.

Oxidation Zone

It is known as the combustion zone. In this zone, feedstock carbon is burned through oxygen. Temperature ranges from 700°C to 1,500°C which is the highest among all zone and exothermic reactions occur in this zone. Air, which is a gasifying agent, is entered in this zone into the biomass feedstock bed. Carbon dioxide proportion is increased, and the oxygen percentage is decreased while using air as a gasifying medium. Following chemical reactions take place:

$C+O_2 \rightarrow CO_2$ -401.9 kJ/mol

$H+1/2O2 \rightarrow H_2O$-241.1 kJ/mol

Gasification Zone

It is known as the reduction zone. Temperature ranges from 800°C to 1,100°C. The reaction is mostly endothermic as follows:

Reaction 1: $C+H_2O \rightarrow CO+H_2$ (+131 kJ/mol)

Reaction 2: $C+CO_2 \rightarrow 2CO$ (+172 kJ/mol)

Reaction 3: $CO+H_2O \rightarrow CO_2+H_2$ (-41.2 kJ/mol)

Reaction 4: $C+2H_2 \rightarrow CH_4$ (-74.8 kJ)

Torrefaction, also known as destructive drying and slow pyrolysis, is a mild pyrolytic process that recently received wide attention of the scientific community as both: the method of the pre-treatment and upgrade of low-quality fuels [Chew and Doshi 2011, Chen et al. 2015, Białowiec et al., 2017], as well as for the production of soil amendment, called biochar [Hekkinen 2019]. This process may be organised at scales ranging from large industrial facilities down to the individual farm [Lehman and Joseph 2009], and even at the domestic level [Whitman & Lehmann 2009], making it applicable to a variety of socioeconomic situations. The study of Macreadie et al., 2017 provided clear evidence that the conversion of beach-wrack to biochar could be a viable environmental solution for dealing with unwanted wrack, offsetting carbon emissions, and providing commercially valuable products. The use of macroalgal biomass for biochar (charcoal) production, with energy co-generation potential, provides a value-driven model to sequester C and recycle nutrients [Ross et al., 2008; Bird et al., 2011]. Biochar has demonstrated applications as a soil ameliorant capable of improving water holding capacity, nutrient status, and microbial ecology of many soils

[Lehmann et al., 2006; Lehmann & Joseph, 2009; Thies & Rillig, 2009]. Results of [Bird et al., 2011] showed that macroalgal biochar has properties that provide direct nutrient benefits to soils and stimulate crop productivity and will be especially useful for the application on acidic soils. [Bird et al., 2011]. In contrast to bioenergy, in which all CO_2 that is fixed in the biomass by photosynthesis is returned to the atmosphere quickly as fossil carbon emissions are offset, biochar has the potential for an even greater impact on climate through its enhancement of the productivity of infertile soils and its effects on soil GHG fluxes [Woolf et al., 2010].

5.5.3 Choice of gasification tests

The choice of the gasification technology was driven by the specific nature of the beach wrack as received. The gasification of carbonaceous solid fuels is a well-known and well-researched process. There are several types of gasifiers: downdraft, updraft, fluidized bed and others. The choice of gasifier technology is largely determined by the nature of the fuel used.

Beach waste is characterized by a very high content of inert substances. Sand and rocks can be a significant part of the mass, depending on the type of waste collection. Of particular relevance to this factor is the mechanized collection method. Also, the bulk density and thermal conductivity of such waste are very low. Limiting the small particle flying process is a major challenge for conventional gasifiers. The thermal conductivity of the fuel is very important in the initial phase of the gasification process, pyrolysis. All of this imposes huge restrictions on the choice of gasification technology.

Another factor in the choice of gasification technology is the requirements for the synthesis of gas composition and tar content. This factor significantly limits the use of synthesis gas. Dirty and tar-rich synthesis gas can only be used as fuel for combustion in boilers. High purity gas can be used as fuel for power and heat generation in internal combustion engine power plants. High purity synthesis gas can be used as a feedstock for chemicals and second-generation biofuels.

The technology with potentially very high gas purity has been selected for beach wrack gasification tests. This utilizes a hydraulic briquetting press system built into the gasifier to increase fuel density and thermal conductivity, which simultaneously performs functions of a fuel compactor, gas leak shutter and dispenser. In the process, the amount of flying fuel particles are minimized. The installation is very compact and transportable. Additionally, the resulting pyrolysis/gasification char is obtained in the form of solid briquettes, which can extend the applicability and improve the logistics of the product.

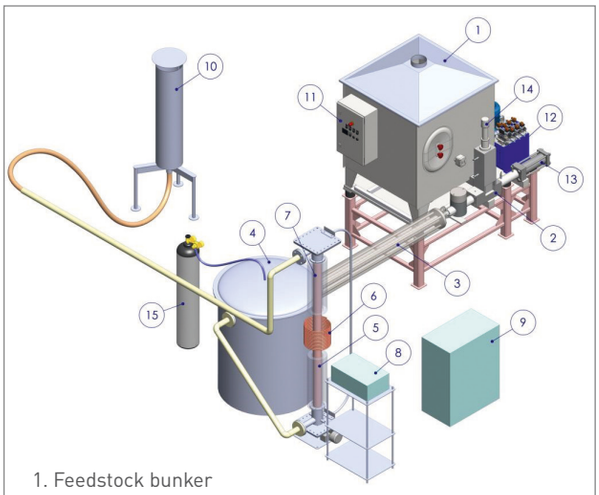
5.5.4 Description of the beach wrack gasification test facility

Thermal gasification tests have been carried out to determine the useful use of offshore waste. Before the gasification tests, the waste samples were cleaned of bulky inert impurities and the samples were dried from the initial 80 % moisture to 20 % moisture content by weight of the wet substance Drying was done by spreading algae waste on a metal fine grid in a 100-150 mm layer and blowing air through this layer at a temperature of 30-40 C. The average drying time was 72 hours. After the drying process, the beach wrack feedstock was packed in airtight polyethene bags and prepared for gasification tests.

Wrack gasification tests were made on an innovative gasification plant for pyrolysis of various wastes and the thermal cracking of pyrolysis gas products (→ Fig. 5.2. The apparatus consists of an extruder-type pyrolizer/gasifier, a pyrolysis product separation chamber, a thermal cracker for gaseous pyrolysis products and a gas burning torch. The gasification process does not use air or oxygen as a gasification agent. The plant has an allothermal gasification process using an external heat source. Nitrogen is the gas that commonly used for inserting in the plant and enhanced process safety. The machine is in continuous operation mode.

In the extruder-type pyrolizer (3), the fuel is compacted in a continuous 42 mm diameter briquette blast, pressed into a heated extruder utilizing a hydraulic piston. The operating temperature of the extruder was set and automatically adjusted to 300-600 °C. The primary reforming of the fuel into pyrolysis gas and coal is carried out in the extruder.

In the pyrolysis product separation chamber (4), the pyrolysis gas is separated from the coal. The carbon is stored in an airtight container. After cooling, the coal is unloaded from the container and sent to a laboratory for analysis. The pyrolysis gas is fed to a secondary high-temperature reformer (6) where the pyrolysis gas is heated to 800–1,200 °C. At elevated temperature, high turbulence thermal tar cracking takes place and the heavy organic gaseous substances are reformed into the synthesis gas components H_2, CO, CO_2. At the output of the secondary reformer, the gas is cooled and the heat



1. Feedstock bunker
2. Hydraulic press feeder
3. Heated extruder
4. Gas and char accumulation tank
5. Secondary gas cracking
6. External inductive heater
7. Gas cooler
8. Inductive heater resonator
9. Inductive heater power box
10. Flare
11. Control cabinet
12. Hydro station
13. Hydrocilinder
14. Prior hydropresser box
15. Nitrogen balloon

Figure 5.2 Experimental gasification plant

consumed in the process is recovered. The resulting synthesis gas samples are analyzed on-site with a portable gas analyzer, and the gas samples are collected in sampling bags for further analysis in the laboratory. The synthesis gas, which is produced by the gasification process is burnt in a torch (10) located outside the space.

5.5.5 Anaerobic digestion tests

Biogas as gaseous energy is derived from organic matter (biomass) by anaerobic digestion or fermentation. Methanisation is an ancient, naturally occurring process where bacteria association disintegrates organic matter. In this study, for anaerobic digestion tests, three types of seaweed were collected at the Gulf of Riga Kemeri seaside: brown, red and green algae. Seaweed has been collected as beach wrack from the embankment piles of washed-up feedstock and had an extensive admixture of sand as well as unpleasant smells. As the first step, organic dry matter content was determined. For instance, red algae had the lowest dry matter, just 3.04 %. Therefore, a simple technique for washing the macroalgae was performed and sand separated as much as possible. However, a lot of sand was embedded in the algal pulp and was not fully separated.

These algae samples were tested regarding the chemical composition of standardized methodologies ISO 6496:1999. For each sample and starter (yeast) dry matter, organic solids and ash content were determined. The analysis was made by standard methods. Full dry matter was determined using equipment Shimazu at 120oC temperature, organic matter composition by drying oven Nabertherm assistance at 550oC. Each group of raw materials was carefully weighed by weighing the starter and thoroughly stirred. All samples were used with the same yeast-digestate from the digester. All algae before analysis and filling in the bioreactors were chopped into 3cm pieces. The 0.75 l bioreactors were charged with 20 g of raw materials and 500 g starter (the weight recorded to 0.2 g accuracy). All data were recorded in the journal of experiments and computer. Bioreactors R2 - R4 was charged with 20 g greasy Brown algae, bioreactors R5 - R7 was charged with a 20 g 24 h tap water held Brown algae, bioreactors R8 - R11 – with around 20 g per hour and the bioreactors R12 - R15 through 20 g greasy and dried Brown algae. Digestate was also weighed, and its dry matter, ash, and organic dry matter content were determined. Measurement accuracy was ± 0:02 pH, ± 0.025 l gas volume and ± 0.1 °C temperature. The produced biogas periodically was measured and CH_4, CO_2, O_2 and H2S composition were determined. Starter/yeast was taken from an active biogas fermentation bioreactor. Biogas production amount was investigated using laboratory equipment consisting of 16 x 0.75-litre bioreactors. For digesters, standard vessels were used. The oven fan provided continuous operating temperature. The gas composition was measured with a gas analyzer GA 2000. Methane, oxygen, carbon dioxide, and hydrogen sulfide content of the biogas was measured, as well as pressure and recalculation to normal gas volume was done. Weighing scales were used (Kern FKB 16K02) and pH measurement was made with pH meter with stationary accessories (PP-50).

In the second study, the Brown algae from Riga Bay seashore were studied separately by applying a variety of pretreatment methods to test actual biogas/methane yield of pretreated algae material. The tests were carried out by similar methods as in the first study to provide a comparison of the testing

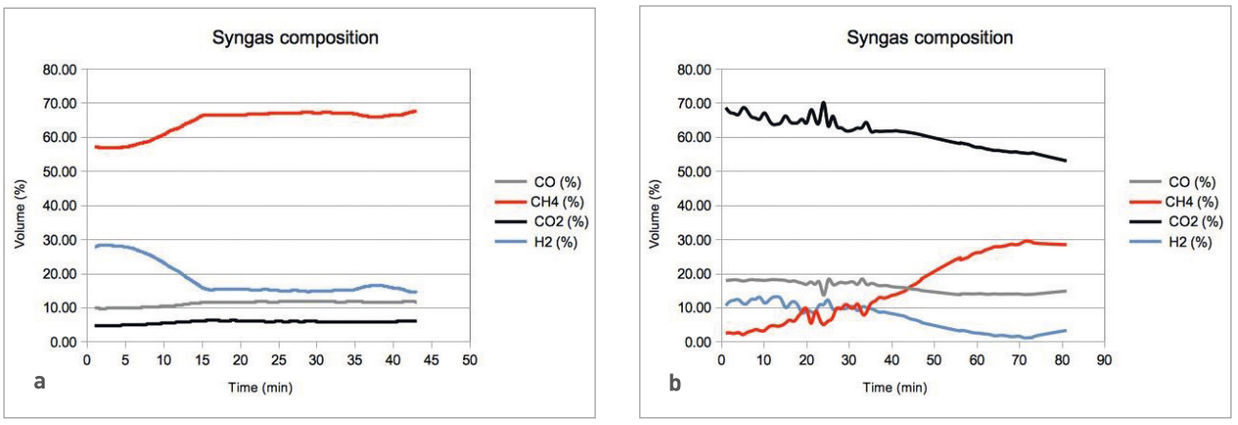


Figure 5.3. Synthesis gas composition in experiment no. 1 (a): stabilization of the gasifier operation occurs within 15 minutes, the inert nitrogen content of the system is not included; and no. 2 (b): no gasifier stabilization, no system inert nitrogen present.

conditions. For freshly collected Brown algae three types of pre-treatment were tested. In the first test, the Brown algae were kept in the water container for 24 hours to reduce salt concentration in the samples. In the second pretreatment option, the Brown algae were rinsed in a stream of water for one hour enabling better separation of sand particles and enhancing the dissolution of the salts with the interaction of larger volumes of freshwater. In the third method, the Brown algae were only dried and the dry part of the sand was separated but still, sand presence remaining. The resulting methane quantities were further compared with the ones, which were obtained from the raw Brown algae without any pretreatment.

5.5.6 Results from beach wrack analysis

Heating (calorific) values of the analysed sample from Stenåsa should be considered as low and the studied substance is not applicable as a fuel (HHV 8.96 MJ/Kg and LHV 7.55 MJ/kg). The proximate composition is characterised by relatively low content of volatile matter (20.4 %), significant content of fixed carbon (11.8 %) and very high content of ash (33.9 %). The ultimate analysis shows a relatively low proportion of carbon (21.1 %) and hydrogen (2.4 %) and high proportions of oxygen (40 %) and mineral compounds. Contents of sulphur and chlorine (0.7 and 0.2 %) should be considered as acceptable for thermal treatment. Analyses of the composition of mineral part show that samples are mainly characterised by a high content of phosphorous, potassium, and nitrogen that makes them perspective for the use in fertiliser production. No problematic concentrations of heavy metals were found.

Thermogravimetric analysis shows that the first decomposition maximum may be observed at >130 °C which should be interpreted as the evaporation of bonded water. The volatilisation of light organic compounds is possible during this stage, while it is impossible to analyse this fact by using only thermogravimetry. Additional measurements are needed for the research of this question. The second maximum takes place at 200-500 °C, which must be interpreted as the pyrolysis of carbohydrates. The content of fixed carbon (>10 %) should be considered as high enough for the production of biochar. Around 50 % of total carbon in feedstock may be retained as fixed char under standard circumstances. FTIR spectroscopy results show the significant share of carbohydrates and carboxylic acids as well as the presence of unsaturated hydrocarbons and amine salts. Our results are consistent with those from [Roberts et al. 2015] who pointed that "Algal biochar is comparatively low in C content, surface area and cation exchange capacity CEC), but high in pH, ash, N and extractable inorganic nutrients including P, K, Ca and Mg". A blending of seaweed and lignocellulosic biochar could provide a soil ameliorant that combines a high fixed C content with a mineral-rich substrate to enhance crop productivity" [Roberts et al., 2015].

5.5.7 Results from marine gasification tests

Gasification tests were performed on the material from Latvia. The tests were conducted with a limited amount of fuel. This limited the duration and number of tests. Of the 1,300 kg collected in marine waste, 219 kg of fuel was obtained after drying. Six gasification experiments were performed, of which 2 were representatively used for detailed analysis (→ Fig. 5.3 and 5.4). Some of the intermediate runs were needed for calibration of the feeding and gas formation ratio to reach close to steady-state

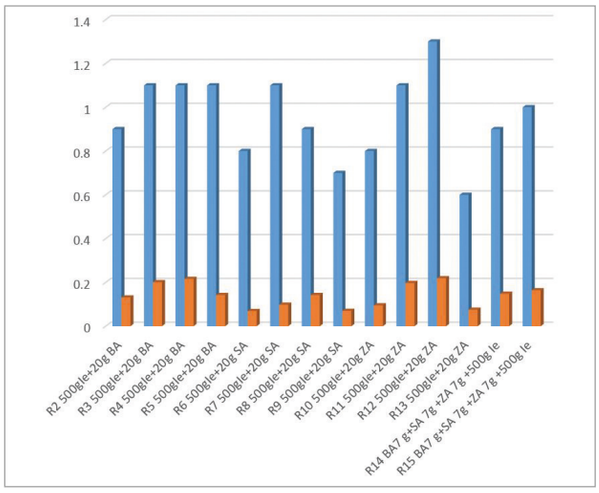


Figure 5.5 Biogas (blue column) and methane (orange column) yields in liters from each bioreactor (x axis). Y axis represents Gasol L.

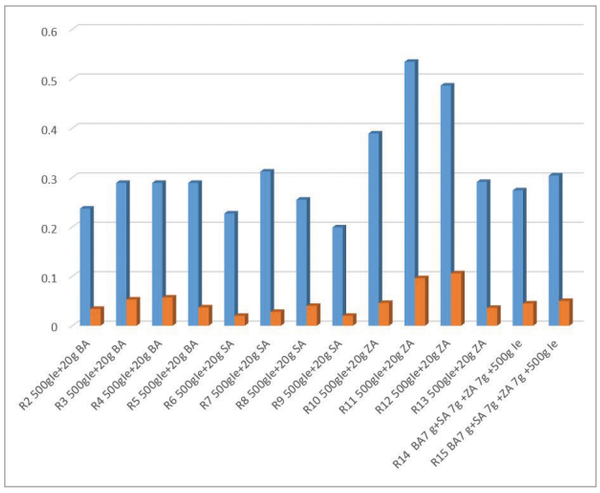


Figure 5.6 Biogas (blue column) and methane (orange column) yields from the various pretreatment of Brown algae-X axis represents the bioreactors and the Y-axis represents the specific gases yield L·g-1dom

of the pyrolysis/gasification process. As a result of the tests, the experience was gained in conducting larger scale beach wrack gasification experiments and in improving the design of the gasifier to work with this fuel further. Both gasification experiments were done under substantially different conditions at different mechanical pressure settings of the pyrolysis zone. The results confirm the initial assumptions and previous experience with this type of gasification plant.

5.5.8 Results from anaerobic digestion tests

The methane from all algae (green, brown and red) collected from the Kameri seaside at the Gulf of Riga represents a very small part of the biogas volume (→ Fig. 5.5). From a carbon perspective, more carbon dioxide was absorbed from the beach wrack composition that was originated at the Gulf of Riga. This shows that the biomass hydrolysis took place, but methanogenesis was weak. Therefore, the raw materials were methane forming bacteria inhibitors. It was dissolved salts in the seawater mixture. The actual salt concentration analysis was not undertaken, as it falls out of the scope of the current biogas/methane yield tests.

Most biogas and methane are obtained from the digesters with dried Brown algae. The results between the washed and unwashed Brown algae are considerably different. Biogas and methane yield was on average higher out of the water stream and Brown algae passively kept in the water for 24 hours. This can be attributed to the ignition effect of the seawater. Anaerobic fermentation microorganisms are influenced to slow down bacteria activity for the fermentation process. Biogas and methane yields from the various pretreatment of Brown algae show that the lowest yield is demonstrated by bioreactor with dried feedstock (→ Fig. 5.6). The largest yield is demonstrated by samples washed in a stream except for reactor R9. We assume it is related to some deviation of the washed-out salts in the particular sample and can be attributed to a mechanical problem. There is a considerable difference between washed and unwashed samples, so it gives a clear recommendation for pretreatment necessity for better yield results even in anaerobic digestion.

Methane content is shown in Figure 5.7. The relatively low methane content in the biogas on average is explained by the fact that the raw materials still possess sea salts, which still inhabit the methane-forming bacteria. The fact that relatively better methane content of biogas digesters demonstrated from dried samples does not support the relationship of less yield with the higher presence of salts (which is the case with dried/unwashed material). However, it should be noted that in these samples dry organic matter content was more than twice compared with others, therefore bacteria in yeast most likely entered into the digestion process before inhibition started to interfere with the methanation.

5.6 Management-related obstacles

Given the ecological functions of beach wrack, the implementation of recreational beach wrack management strategies that work with rather than

against nature is a necessary step towards more sustainable use of beaches. According to Vieira et al., 2016 "Wrack removal may cause ecological problems by disrupting pathways of decomposition and nutrient exchange between marine and terrestrial ecosystems, which is the basis for primary production and food chains of nearshore waters". It may also alter the physical characteristics of the beach, causing changes in the composition of supralittoral invertebrates, higher erosion of the beach profile, and loss of the frontal dune [Vieira et al., 2016]. One mitigation strategy might be to educate beach users to understand the ecological value of wrack to coastal wildlife, and that this organic material needs to be left on some sections of beaches. The local factors should also be considered in human disturbance assessments: (a) beach type; (b) wrack debris features and (c) specific density and composition of individual species associated with wrack [Vieira et al., 2016]. To achieve this, ecologists and coastal recreational managers should work and plan together sustainable management strategies that do not inflict generating environmental and economic losses [Vieira et al., 2016].

5.7 Administrative and legal obstacles

Throughout this project, it was found from local authorities that beach owners, municipalities, or cleaning companies conduct the cleaning of beach wrack deposits every year on some selected beaches. This process is called "beach grooming" and is common practice in other regions of the Baltic Sea, where considerable amounts of beach wrack are accumulated, particularly on the sandy beaches and less frequently on the rocky shorelines. The beach wrack removal differs from the beach to beach and also among Baltic countries, as the accumulation on beaches varies between coastal sections and the existing management standards. In Sandy beaches, the removal operation is made by grid bucket method that is a tractor with a fork in the form of a rake (grid bucket) and usually placed in a pile-up on the beach. Most local authorities carry out the beach wrack removal operations mainly during the summer season. After the touristic period, the beach wrack piles up on the beach are pushed back in the water. In the Baltic Sea, there are various traditional uses of the accumulated beach wrack. For instance, it is used by the farmers to make compost, fertilizer, and fuel for recovering green areas and livestock. Besides, beach wrack has been used as packing and construction material. Apart from the agriculture applications, beach wrack is used for making insulation materials (roofs, interior walls and basement ceilings).

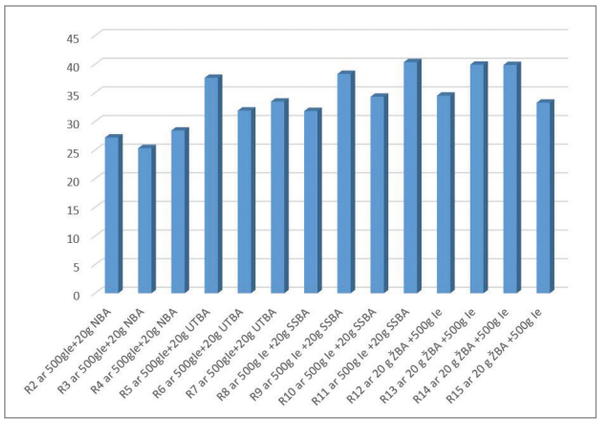


Figure 5.7 Methane content % on average of the different pretreated samples in different bioreactors

5.8 Potential solutions associated with the ecological dimension, targeting network-based, local and transregional opportunities

The collection and management of beach wrack pose a financial burden and a range of challenges for local communities, municipalities, and interested stakeholders and are also often in direct conflict with measures to safeguard the environment. Some of the challenges are the significant cost effect for beach cleaning, the organizational challenge for the municipalities to clean, transport and store the "organic waste". To address this conflict and to balance opposing interests, CONTRA conducts a fair and comprehensive evaluation of all environmental, social, and economic aspects of beach wrack management. This evaluation includes ecological impacts of beach wrack collection, industrial cycles of beach wrack processing, and value chains of beach wrack-based products or services. Potential products and services include fertilizer, soil improvers, biochar, biocover, coastal protection, biogas production, and water quality improvement.

Based on the experience from the gasification tests, it can be concluded that beach wrack as thermal treatment feedstock is suitable for use for gasification. When analyzing the potential application of gasification technology for the treatment of the beach wrack, it is essential to take into account the fact that under real conditions the process can be energy-intensive due to the need for beach wrack drying. However, through designing an efficient recovery of the heat it is possible to redirect a major part of the heat for low-temperature drying,

therefore, improving the overall energy balance of the treatment process. Moreover, the high content of inert substances in the fuel is not an obstacle to the use of tested technology. If drying is applied as low energy input the gasification of the beach wrack is a very suitable method due to flexibility in coping with high ash contents (high concentrations of sand particularly in beach collected feedstock) as well as the economical and logistical arguments that may gain higher importance in the choice of upscale methods. The high level of methane has been quite specific and unique in the course of the tests. It may be attributed to a specific pressure and indirect heating conditions which deserve further analysis by applying repetitive test runs with a larger amount of the feedstock to gain a more continuous process. It may have far-reaching new opportunities for small scale distributed beach wrack utilization systems in this region.

It is recommended to continue research on widening the gasification method to integrated drying systems and improved energy recovery to elaborate on practical upscale solutions. Additional comparison on biogas production out of the beach wrack can be made in the process of anaerobic digestion, which is an alternative approach when higher moisture content feedstock is used combined with other wet waste processing like water treatment sewage sludge.

For anaerobic digestion, the results show that for better yields rinsing of seaweed before feeding into anaerobic digestion is preferable. In cases where it is not possible to do biogas/methane yields will be negligible and recovery of the waste into biogas will not be economically feasible. With or without pretreatment seaweed biomass can be used in the co-fermentation of other waste streams like sewage sludge or manure. Such co-fermentation will optimize the C: N ratio and will neutralize the inhibiting effect. For clarification of the optimal process parameters, further studies and tests are recommended.

5.9 Conclusions

The study includes the performance of gasification technologies on wrack material for carbon-based feedstock thermal recovery and testing out biogas potential from algae using anaerobic digestion equipment. The analysis is based on beach wrack from Öland, Southern Sweden and Latvia. The results from gasification tests performed on material from Latvia suggest that the studied samples are suitable for the use as a feedstock for the production of biochar and gasification application for the regeneration of the beach wrack material. The quality of the char and synthesis gas produced is consistent with the original concept of gasification biomass although beach wrack, in general, has much higher ash content than other biomass waste feedstocks, and the presence of a high concentration of inorganics require proper gasification process conditions. For the anaerobic digestion, the results show that from the coast washed beach wrack, a small amount of methane can be generated per dry organic matter if there is no pretreatment and conditioning of the samples undertaken. The results confirm that washing of Brown algae as pretreatment for anaerobic fermentation avoid salts inhibition and thus can make good use of biomethane production. With the pretreatment of Brown algae in running water, the feedstock is well suited for good volume biogas generation for energy recovery and use in other applications of bio SNG.

Our goal in this study is to develop a practical framework for obtaining a uniform sample recommendation on thermal recovery and relevant analytical performances that are targeting administrative, political and regional communities. To improve future research and promoting innovative and sustainable knowledge among society, we make the following suggestions from our study design:

- The results from gasification tests performed on material from Latvia suggest that studied samples are suitable for the use as a feedstock for the production of biochar and gasification application for the regeneration of the beach wrack material.
- The quality of the char and synthesis gas produced is consistent with the original concept of gasification biomass. Although beach wrack, in general, has much higher ash content than other biomass waste feedstock and the presence of a high concentration of inorganic materials, requires proper gasification process conditions.
- For the anaerobic digestion, the results show that from the coast washed beach wrack, a small volume of methane is generated per dry organic matter if there is no pretreatment and conditioning of the samples undertaken.
- The results confirm that washing of Brown algae as pretreatment for anaerobic fermentation avoids salts inhibition and thus can make good use of biomethane production.
- Beach wrack may be employed on reclaimed land when mixing with straw from cattle boxes

and liquid manure for growing of feed corn on the new land for agriculture. It probably increases the decomposition of the soil remaining humus from the pine tree forest. Ordinary composting is also possible if pollutant concentration is not too high.

- There is a possibility of bio-coal that can be produced from beach wrack that would be mixed with sediments to provide stabilization of road-deposited sediment pollutants.
- The introduction of beach wrack as an energy resource rather than waste can stimulate market implementation.
- Of major importance is to simplify administrative procedures for beach wrack management and continue its energy development.
- Raising the awareness of the flexibility and new applications that drive gasification and anaerobic digestion technologies to gain greater prominence.
- Thermal energy recovery and relevant analytical performances can be considered as energy efficiency approaches for a tremendous variety of products among them beach wrack biomass.
- Globally there is a strong strategic desire to use regional indigenous energy resources to produce the energy and products needed for regional economic growth. Beach wrack is one of the regional indigenous energy resources for Baltic countries.
- Gasification facilities are diverse in the development of safe designs and safe operations to address multiple energy security concerns.
- Gasification and anaerobic digestion technologies can meet market needs throughout the world and contribute to zero waste management.
- Innovative work is underway on thermal recovery and relevant analytical performances towards circular economy solutions for the management of beach wrack residues to bioenergy via gasification and anaerobic digestion.
- It is interesting to quantify the total amount of beaches in the Baltic Sea region, including the managed, unmanaged and tiny beaches. As there is a need to model and monitor the aquatic environment.

5.10 Strategic principles of ALREA and practical recommendations, which target administrative people and politicians

The introduction of beach wrack biomass as a source of energy can stimulate market implementation.

The major importance is to simplify administrative procedures for beach wrack management and continue its energy development.

Raising the awareness of the flexibility and new applications that drive gasification and anaerobic digestion technologies to gain greater prominence.

Gasification and anaerobic digestion waste-to-energy processes can yield a tremendous variety of products among them beach wrack biomass.

Globally there is a strong strategic desire to use regional indigenous energy resources to produce the energy and products needed for regional economic growth. Beach wrack is one of the regional indigenous energy resources for Baltic countries.

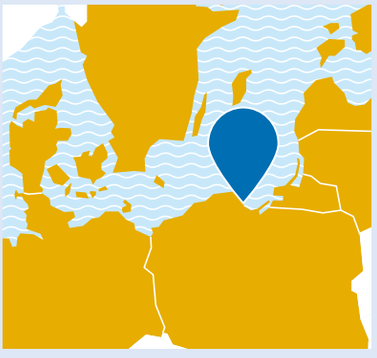
Gasification facilities are diverse in the development of safe designs and safe operations to address multiple energy security concerns.

Gasification and anaerobic digestion technologies can meet market needs throughout the world and contribute to zero waste management.

Innovative work is underway on gasification technologies towards circular economy solutions for the management of beach wrack residues to bioenergy via gasification and anaerobic digestion.

It is interesting to quantify the total amount of beaches in the Baltic Sea region, including the managed, unmanaged and tiny beaches. As there is a need to model and monitor the aquatic environment.

Case study 6a: Nutrient and pollutant flux to coastal zone originating from decaying algae & plants on beaches (WAIT)
Case study 6b: Beach wrack treatment in reed bed systems (FERTIWRACK)



Case study partner – WAIT: Institute of Oceanology of Polish Academy of Sciences

Location of the case study: Puck Bay, Poland

Aim of the case study: To evaluate beach wrack associated transport of substances from sea to beach, and identify beachcast removal impact on the ecosystem.

Test/research done: Analysis of beachcast and sand chemicals impacted by decaying algae, biodiversity studies of beachcast habitats, accessing the additional benefit of beach wrack removal by taking out excess nutrients and harmful substances from the environment.

Staff involved: Siedlewicz G., Kotwicki L., Szubska M., Korejwo E., Grzegorczyk K., Walecka D., Bełdowski J., Bełdowska M., Graca B., Staniszewska M

Case study partner – FERTIWRACK: 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: To transform beach wrack into fertiliser or structure-forming material using natural based solution – reed bed system.

Test/research done: 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

Staff involved: Kupczyk A., Kołecka K., Gajewska M.

The Chapter presents two Case Studies, the more theoretical one (WAIT) and the more practical one (FERTI-WRACK), which were fulfilled in Poland in close relation to each other and focused on the same study area.

Authors: Kupczyk A., Kołecka K., Gajewska M., Siedlewicz G., Szubska M., Grzegorczyk K., Walecka D., Kotwicki L., Bełdowski J, Bełdowska M., Graca B., Staniszewska M.

6.1. Location and geographical description

Almost 500 km of the Polish coastline are characterised by sandy sediments practically without any vegetation. The only exception is the Puck Bay, the shallow area of the Gulf of Gdansk, and in particular an area located near the town of Puck. These waters should be considered as the most productive area along the entire Polish coast. For this reason, two closely located beaches, managed in Puck and unmanaged in Rzucewo, have been selected for Case Studies 6a and 6b (→ Fig. 6.1). The model facility of the reed bed system (case study 6b) was built in the area of the Wastewater Treatment Plant in Swarzewo.

Puck Bay creates specific Baltic micro-habitats, e.g., low salinity, the high influx of freshwater from rivers and groundwater sources [Kotwicki et al., 2014]. According to the scale developed by [Brown & McLachlan, 1990], the beaches in the Puck Bay area are intermediate with medium to fine sand. The swash water salinity ranges from 3 to 8 PSU, and its temperature varies seasonally from 0 to 25 °C. The macrophytic community is more abundant than in other Baltic Sea parts [Kruk-Dowgiałło, 1996].



Figure 6.1: Localisation of sampling place [source: google map view]

6.2 Beachwrack – theoretical background

Beach wrack occurs naturally, practically on all beaches worldwide, including the Baltic beaches in Poland. The material of beach wrack is washed ashore by wind, waves and tides. Retreating waves can also transport them back into the water system [Macredie et al., 2017]. The occurrence of beach wrack supports various small organisms and microbes. It also provides important habitat for invertebrates and shorebirds (food, shelter, nesting). Beach wrack is also essential in protecting the shoreline; it constitutes a physical barrier that dissipates the wave energy (reducing its impact force). Beach wrack contributes to reducing the erosion processes in winter. Seagrass has got fibrous composition which allows us to bind the drifter sand and strengthen coastal dunes. On the other hand, decaying macroalgae were also identified as sources of nutrients and heavy metals (Hg), and other pollutants concentration in coastal sediments. Concerns about beach wrack polluting beaches have led to research into its removal and industrial processing.

6.3 Beach wrack as a problem

Drifting algal mats have recently become a problem in shallow, eutrophic seas worldwide. On the one hand, the excess organic matter washed ashore or deposited on the seabed enhances the growth rates of suspension feeders. On the other hand, it can create local hypoxia events followed by changes in zoobenthos abundance, species composition and food web. Marine plant detritus plays an essential role in the global carbon cycle and exceeds three-fold the amount of carbon stored in living marine plants. Coastal marine waters are the critical areas of plant detritus production and storage. Owing to their permeability, sandy shores are very efficient converters of organic matter. It is necessary to know about detritus production and its biomass to understand the importance of sandy shores in organic matter turnover [Kotwicki et al., 2005].

Furthermore, beach wrack constitutes not only an environmental problem but also a socio-economic problem. The material accumulated on the seashore is not an aesthetic sign. Besides, the process of its decomposition is accompanied by an unpleasant smell. Therefore the adverse consequence

	MANAGED BEACH	UNMANAGED BEACH AREA	
	Puck	Rzucewo 1	Rzucewo 3
Beach [m]:	100 × 13	100 × 3-15	100 × 2
Beach wrack coverage [%]:	1 - 2	8 - 89 (37)	10 - 100 (47)
Beach wrack area [m²]	1 - 54 (25)	32 - 966 (312)	10 -153 (70)
Thickness [cm]	1	1-38 (15)	1 - 14 (6)
Volume [m³]	0.1 - 0.5	3 - 203	1 - 23
Weight [kg/m² ww]	0.1 - 1.1	1.8 - 168	8 - 400

Table 6.1: Calculated values of basic parameters for the studied areas
**in brackets average values*

of beach detritus for coastal tourism is obvious [Balance et al., 2000, Malm et al., 2004]. As a result, it is a severe problem for the local authorities of seaside resorts, where the economy is based mainly on the tourism industry. Beach wrack can also be a potential point source of environmental contamination. Both filamentous algae and higher plants accumulate chemicals from seawater and to some extent, sediments. Existing studies show that in the case of heavy metals algae are enriched in, i.e. mercury and cadmium [Beldowska et al., 2015, Franzen et al., 2019], especially in comparison to concentrations usually encountered in the sandy beaches.

6.4 Beach wrack quantity and composition (the results from WAIT)

Case study 6a included an assessment of beach wrack quantities and analysis of beach wrack chemical and biological composition, and calculation of depuration rate from pollutants, resulting from the removal of organic beachcast from the beaches. Field studies were conducted monthly throughout the year. The deposited organic matter/beach wrack material was analysed in terms of quantity and quality. Chemical analyses included basic environmental parameters, nutrients, organic pollutants, heavy metals, and other harmful compounds. Also, macro- and meiofauna samples were taken, the rate of decomposition of organic material was estimated, and the amount of litter on the beaches was calculated.

Dominant species in beach wrack material practically all year round were higher plants: *Potamogeton pectinatus* and seagrass *Zostera marina* with no significant differences between sites in qualitative terms. On the other hand, concerning the coverage expressed as a percentage or per square meter value and the thickness of the beach wrack, the calculated total volume and weight of the material deposited on the unmanaged beach was many times higher, with values reaching several hundred kilograms per square meter of the beach (→ Table 6.1).

Macrofauna organisms were numerous in both areas. However, the managed beach was characterised by the higher biodiversity and number of species. Higher total biomass was observed in the unmanaged area, but this was due to opportunistic species adapted to live in various unfavourable environmental conditions. The insect larvae chironomids and benthic oligochaetes are examples of such species.

As far as garbage on the beach is concerned, the managed beach was more than twice as polluted with plastic. This is not a surprise, due to the touristic character of the place. The litter count for both sites was the largest in June-July 2019, in the middle of tourist season, and gradually decreased later. The most frequent items were polystyrene/plastic pieces. And in case of the managed beach in the summer season, those were glass bottles and empty aluminium cans. Throughout the year, over 700 items were found in Puck and nearly 300 in Rzucewo. The total weight of the litter found in Puck and Rzucewo was 3.05 kg and 3.77 kg respectively. In Puck, there was mainly touristic litter (plastic cutlery, cigarette butts, etc.) while in Rzucewo the litter consisted more of household goods and building construction litter.

6.5 Chemical contents in beach wrack (the results from WAIT)

In the presented case study 6a beach wrack, sediments and water were investigated for the presence of heavy metals, methylmercury, nutrients,

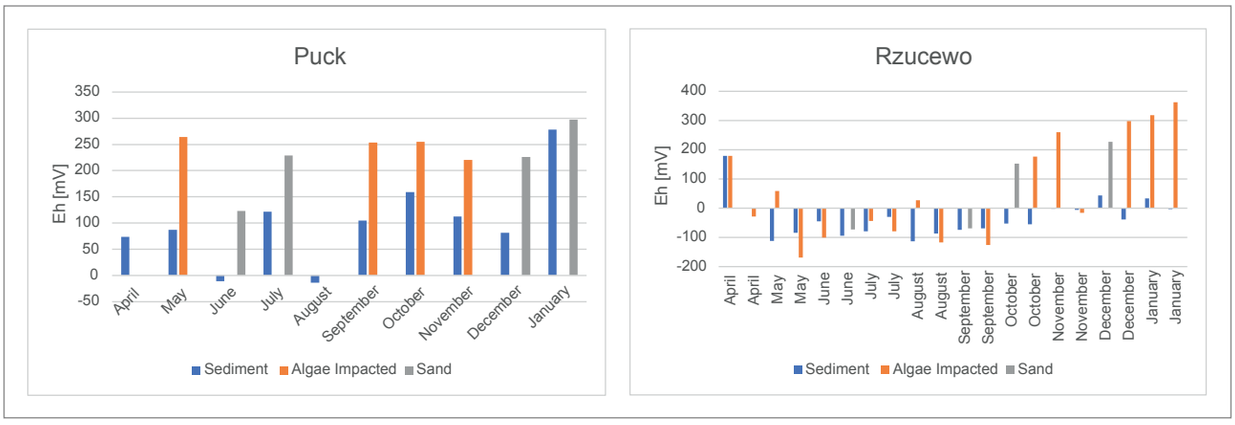


Figure 6.2. Change of the redox potential [Eh] for managed (a) and unmanaged (b) sites

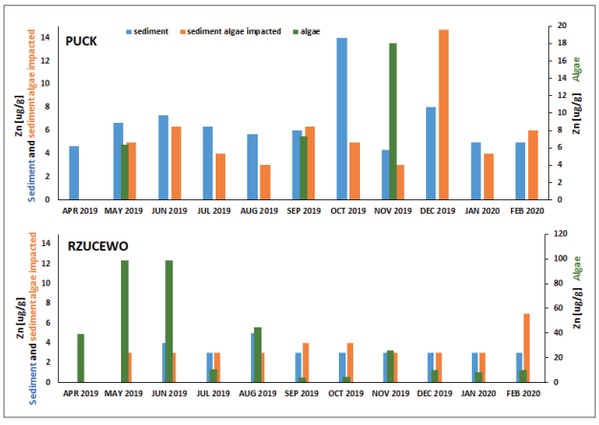


Figure 6.3. Zinc concentrations from in situ measurements in sediments with and without the impact of algae on managed (PUCK) and unmanaged beaches (RZUCEWO)

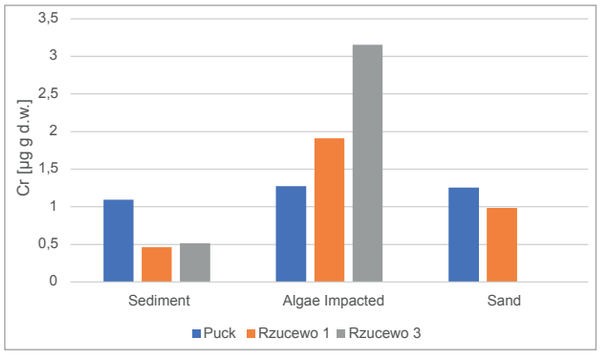


Figure 6.4. Chromium concentrations in sediments with and without the impact of algae in managed (PUCK) and unmanaged beaches (RZUCEWO) in July 2019.

Bisphenol A (BPA), Nonylphenols (NP), octylphenols (OP), Polycyclic aromatic hydrocarbons (PAHs,) and Polychlorinated biphenyls (PCB).

Redox potential. One of the important factors measured during the sampling campaign was the redox (oxidation-reduction) potential. Redox reactions are essential to major element cycling to many sorption processes, to trace element mobility and toxicity, to most remediation schemes, and to life itself. The in situ measurements in surface and pore water show significant oxygen depletion in the warm period and lower annual oxygen levels in the area impacted by algae (→ Fig. 6.2). Moreover, the measurements' results indicate that oxygen consumption during algae decomposition influences an area more expansive than just that covered with algae wrack, resulting in oxygen depletion in pore waters not directly impacted.

Heavy metals are natural elements of the Earth's crust, but their discharge to the environment due to anthropogenic activity overwhelms their natural concentrations. The most toxic heavy metals that pollute the Baltic Sea include mercury (Hg), cadmium (Cd), arsenic (As), and lead (Pb) [Szefer, 2002]. Heavy metals can be toxic even at very low concentrations since they tend to be accumulated in marine organisms and biomagnify along the trophic chain. Consequently, they can threaten final consumers – humans [Zaborska et al., 2019]. The concentration of heavy metals in sediments does not exceed the thresholds values given in Journal of Laws (2002) and HELCOM core indicator.

However, in the case of Zn, one order of magnitude higher concentration was observed in the beach wrack in the unmanaged beach compared to sediments (→ Fig. 6.3).

Also, chromium concentrations are worth further investigations. The observed difference between Cr levels in sand from the managed beach (Puck) and sand impacted with algae (Rzucewo1 + Rzucewo3), as well as sediments from both areas is significant (→ Fig. 6.4). Measured values indicate that an intake of Cr from sediments by algae may occur in the heavily overgrown Rzucewo site (unmanaged

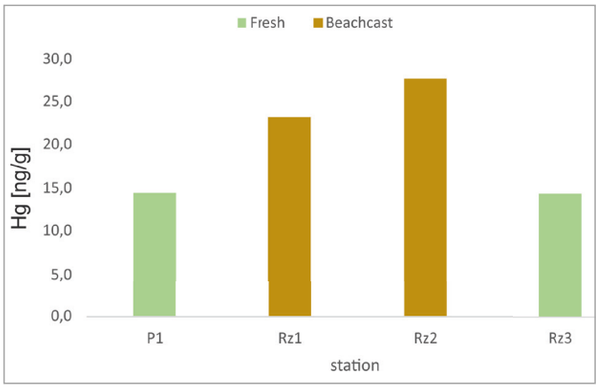


Figure 6.5. Total mercury concentration in live algae at the managed site (P1), decaying beachcast at the unmanaged site (Rz1, Rz2) and live algae at the unmanaged site (Rz3)

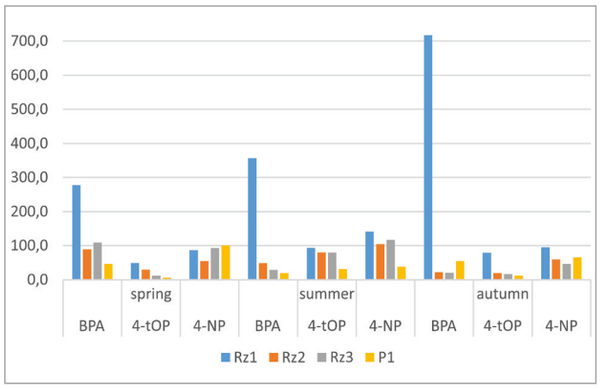


Figure 6.6. Concentrations of bisphenol A (BPA), 4-tert-octylphenol (4-t-OP) and 4-nonylphenol (4-NP) ng.g-1 dw in microalgae depending on season and station

site). Afterwards, the element can be transferred to the beach sand due to wracked algae decomposition. Although the chromium data are only available for one sampling campaign (July 2019), the preliminary results suggest that beach wrack can be a source of metals to the coastal environment.

Methylmercury (MeHg) is the most toxic and dangerous form of mercury occurring in the environment. MeHg is highly bioaccumulative in organisms and undergoes biomagnification via the food chain. The environmental conditions promoting methylation processes and production of MeHg are anoxic conditions, high contents of organic matter, and specific microorganism. All of those conditions are present in the beach wrack. Results from the measurements of MeHg in sediments and sand do not give a definite answer if the beach wrack promotes the production of MeHg. For the Rzucewo site (unmanaged site) in June 2019, the highest concentration of MeHg (20 pg g-1 d.w.) was measured in algae impacted beach sand in comparison to the not impacted (8 pg g-1 d.w.) and sediments collected from water (5 pg g-1 d.w.). However, in July 2019 the highest concentration was in sediments collected from water (45 pg g-1 d.w.) in comparison to algae impacted beach sand (6 pg g-1 d.w.) and not impacted sand (<LOD). In case of the managed beach in Puck, both in June and July 2019, MeHg was detected only in sediments at low concentration (8- 10 pg g-1 d.w.), and in the sand from beach concentration was below the detection limit (<LOD).

The mercury concentration (total mercury) on the managed beach (P1), in the sites with algae, is lower than on the unmanaged site, where decomposing wrack was collected (Rz1 and Rz2) (→ Fig. 6.5). However, in the unmanaged site, mercury concentrations in live algae (Rz3) were similar to those at the managed site. This indicates, that although biological material from the bay accumulates Hg at the same rate, and is characterised with the same mercury concentration at both sites, accumulation does not stop after landing. Decomposed material on the beach wrackage site is rich in organic matter and continuously builds up Hg concentration. This is probably caused by excellent sorption capabilities of decaying plant and algae material. It may capture mercury from coastal water, acting as a filter for surf water. This means that unmanaged beaches may transfer mercury from beachcast via accumulation in live algae and subsequent release, therefore enhancing mercury flux to the beach from local sources. Analysis of depth profiles indicated that mercury is released from beachcast into the groundwater of unmanaged areas.

Bisfenol A (2,2-bis-(4-hydroksyfenylo)propan - BPA), 4-tert-oktylofenol (4-t-OP) and 4-nonylofenol (4-NP)

Bisphenol A and 4-nonylphenol were identified in all kind of samples, the 4-tert-octylphenol in some samples was not detected (especially in microalgae from July and in water from November). The highest concentrations were observed for BPA in pore water (avg. 6,000 ng.dm-3) or pore water under algae (avg. 400 ng.dm-3), macroalgae (avg. 214.3 ng.g-1 dw[1]) or sediments (avg. 2.9 ng.g-1 dw). It was a noticed enrichment in pore water or pore water under algae compared to surface water (the concentration ranging from several-fold increase

1 dw – dry weight

STATION	C	N	P
P	298	21	1
Rz2	406	25	1
Rz3	421	23	1
Rz1	559	33	1

Table 6.2. Molar ratio of C:N:P in wrack at stations P, Rz1, Rz2 and Rz3

to 67 times higher) for all phenols. Concentrations of phenols depending on season and site were the most noticed for microalgae (→ Fig. 6.6). The maximal average concentration of microalgae for the site was achieved on station Rz1 (BPA – 450.7; 4-t-OP – 74.1 and 4-NP – 107.8 ng.g-1 dw), the lowest one – for the references station P1 (40.6; 16.6; 68.5 ng.g-1 dw respectively). These concentrations were the highest for autumn.

Carbon, nitrogen, phosphorus and water-extractable forms of phosphorus and nitrogen in beach wrack

Forty-six beach wrack samples collected from April to November at 4 stations were analysed.
Usually, at all stations within a given month, total carbon Ctot), total nitrogen (Ntot) and total phosphorus (Ptot) content in detritus decreased as follows: the wrack from the water was characterised with the highest concentration of studied elements, the wrack from a surface layer of beach sand contained slightly lower concentrations, while wrack buried beneath a layer of beach sand showed the lowest concentration. This reflects the gradual decomposition of organic matter after its deposition to the beaches. The exception was the R1 station, where wrack was the most degraded as indicated by the highest value of the C: N: P ratio (→ Table 6.2), and relatively low concentration of water extractable forms of nitrogen (N-NH4) and phosphorus (P-PO4) (→ Fig. 6.7). Detritus probably lingers on the beach for a long time in this area. Generally, wrack accumulated at unmanaged beaches (Rz1, Rz2, Rz3) was more decomposed in comparison to wrack from the managed beach (P) (→ Table 6.2).
Rough estimation show, that in beach wrack accumulated along 100 m of the coast (mean dry wet) at unmanaged stations (Rz1, Rz3), the weight of phosphorus ranged from 18 to 36 kg (→ Fig. 6.8). Considering that the phosphorus concentration (median) in algae samples classified as living is known, it can be roughly calculated, that such a load delivered to the seawater could be responsible for producing 6 to 29 tonnes of phytoplankton biomass (→ Fig. 6.8).

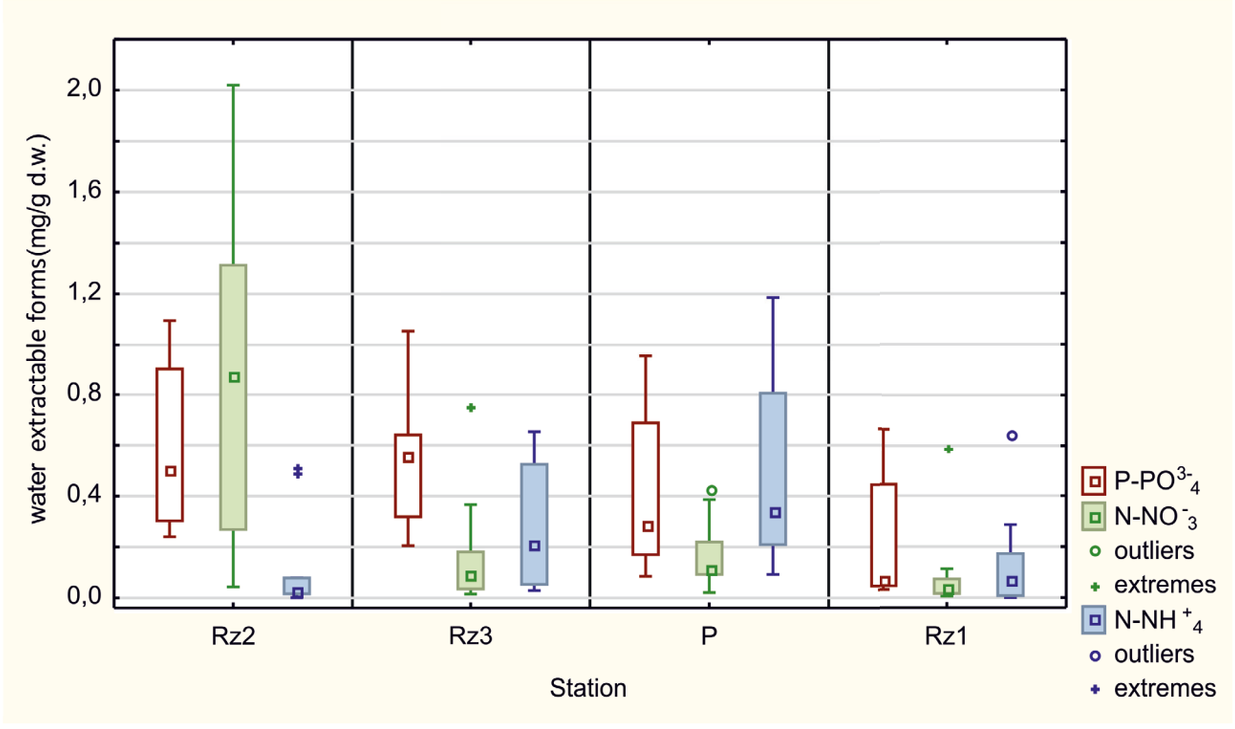


Figure 6.7. Seasonal and spatial variability (a) carbon (Ctot), (b) nitrogen (Ntot) and (c) phosphorus (Ptot) in wrack sampled from surface water and two layers of beach sediments at three stations.

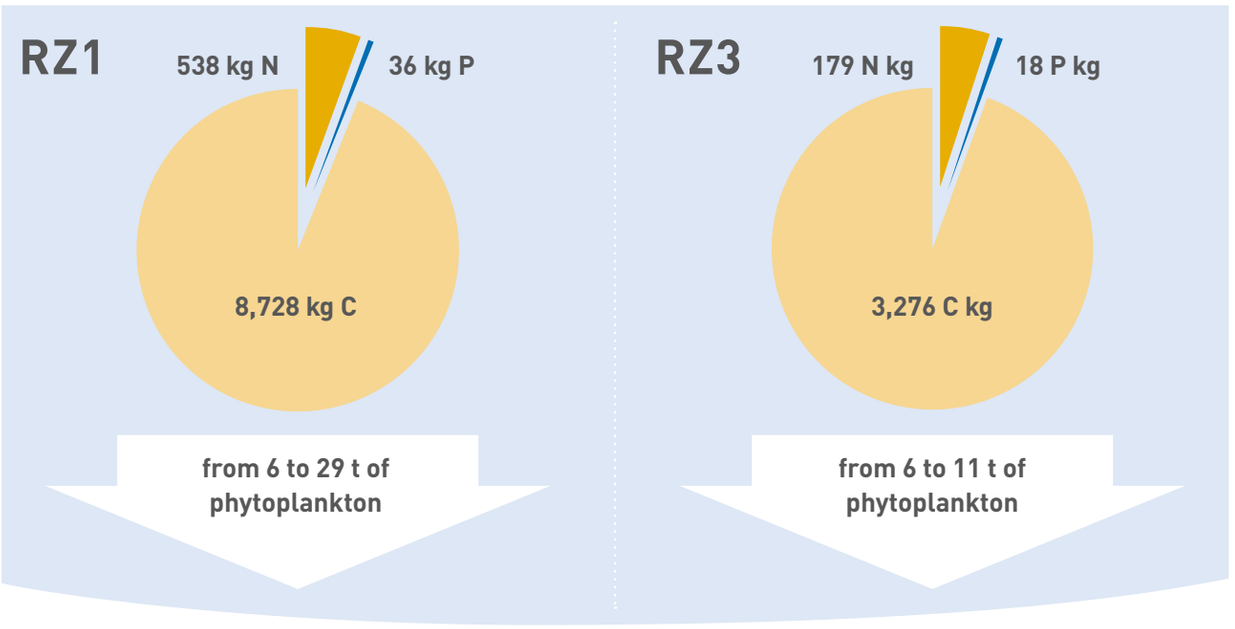


Figure 6.8. Mean load (kg) of phosphorus, nitrogen and carbon accumulated at 100 m of unmanaged coast (station Rz1 and Rz3) and potential production of phytoplankton biomass (assuming total decomposition of beach wrack and P limitation).

6.6 Technology tested

To transform beach wrack from nuisance to resource, the Gdańsk University of Technology, (under CONTRA case study 6b FERTIWRACK), has tested the possibility of a reed bed system used to obtain fertiliser from beach wrack as a final product.

The reed beds 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 [Kołecka, 2019]. The basic principle of reed systems operation is based on the use of processes naturally occurring in wetland ecosystems in controlled environmental conditions [Gajewska, 2019]. Model facility (→ Fig. 6.9, foto → Fig. 6.10) 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 deposit. Material charging was done manually and carried out by an authorised person.

First, the discharging of beach wrack took place in October 2019. Then the pilot system rested for 5 months. In April 2020, the Gdańsk University of Technology's research team began to regularly discharge beach wrack material into the reed bed system's pilot plant installation at the WWTP in Swarzewo. Changes in the reed bed system's material after one month of operation are presented in → Fig. 6.11.

Each month, the beach wrack collected for research was at a different decomposition stage, reflecting its basic parameters (→ Fig. 6.12). The water content ranged from 94.6 % (July) to 95.5 % (June), the content of the mineral substance – from 43.9 % (June) to 58.6 % (July), and the organic substance content – from 41.4 % (July) to 56.1 % (June). The higher the mineral substance content was registered, the higher the algae decomposition rate was observed. Changes in the material are presented in → Fig. 6.13. The bed material is dewatered (→ Fig. 6.14) and subjected to a stabilisation process (→ Fig.

Figure 6.9. Scheme of pilot reed system based on cubic modules [A. Kupczyk's study]

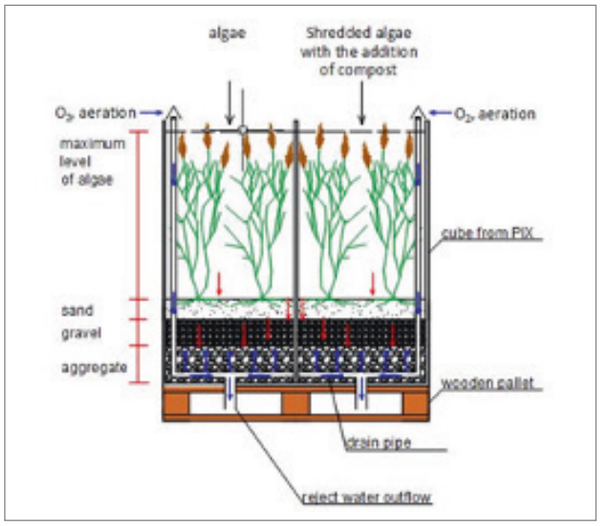






Figure 6.10. Constructed pilot plant of RBS at WWTP in Swarzewo: (a) reed in the RBS (August 2020), (b) two cubic pilot plant RBS (October 2019), photo: A. Kupczyk



Figure 6.11. Constructed pilot plant of RBS at WWTP in Swarzewo: (a) reed in the RBS (August 2020), (b) two cubic pilot plant RBS (October 2019), photo: A. Kupczyk

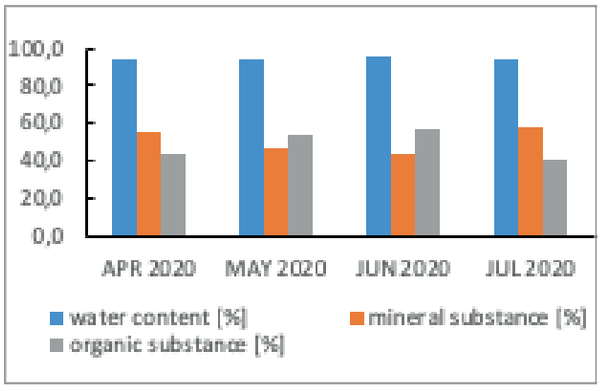


Figure 6.12. Changes in fundamental parameters of collected raw beach wrack in time [A. Kupczyk's study]

6.15), which is indicated by a decrease in the content of organic matter.

One-month changes in the basic parameters of the material discharged to RBS are presented in → Fig. 6.16.

In the case of reject water, it isn't easy to establish a repeatable test scenario. Every month a different amount of reject water from the reed system was collected. The difference depends on the vegetative needs of the reed and weather conditions occurring in that specific month. The quality of reject water and it changes after supply of fresh material to deposit is presented in → Table 6.2.

6.7 Management-related obstacles

The reed bed system is characterised by simple construction but requires proper design and professional performance. The lack of precision in the facility's construction may contribute to the subsequent incorrect operation of the system.

The exploitation time of the deposit is relatively long, but it consists of the start-up period, full exploitation and emptying of the system. The deposit start-up period can last for about 2 years, which can be an obstacle to choosing this method.

The beach wrack material properties are unknown, so it is difficult to determine the appropriate dose and frequency of charges. The system works in an altering cycle. There are two phases of work: (i) irrigation – the supply of raw material and (ii) rest–break in the feeding of deposit. There are no precise guidelines for the time between charges. The intervals between subsequent irrigations will 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 the next irrigations may result in better dewatering and stabilisation efficiency.

Also, the reed bed system, depending on the forecast amount of beach wrack material that will be

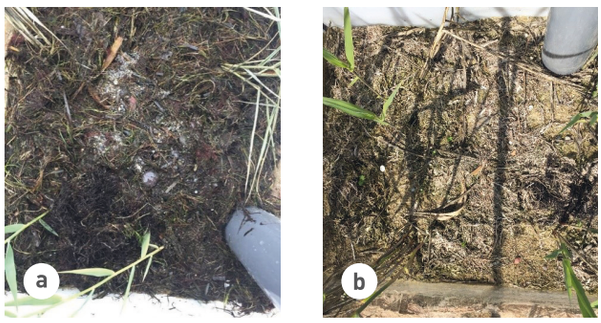


Figure 6.13. Beach wrack material in the reed bed system: (a) Test supply of beach wrack to RBS, 18 November 2019 [photo: A. Kupczyk], (b) beach wrack in RBS after 6 months, on 27 May 2020. Photo – A. Kupczyk

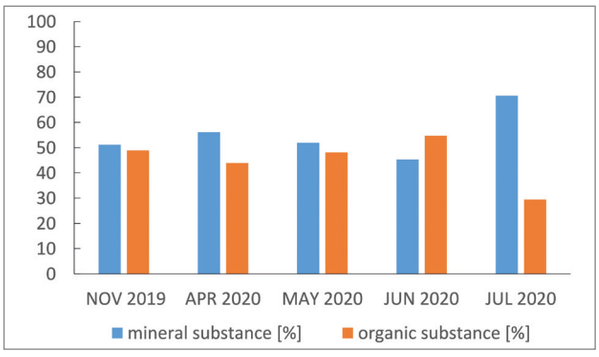


Figure 6.15. Changes in mineral and organic substance in beach wrack material (without fresh discharging) [A. Kupczyk's study]

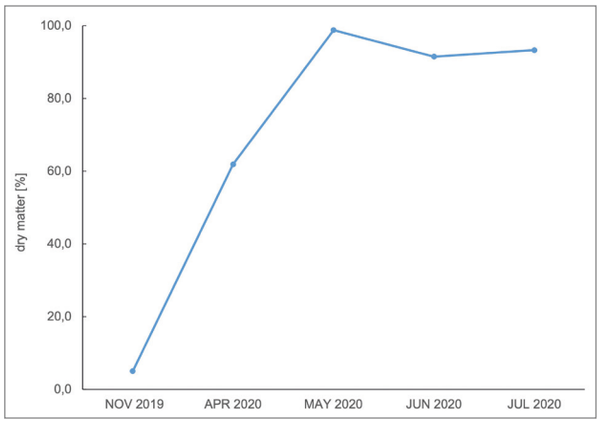


Figure 6.14. Changes in dry matter content in beach wrack material (without fresh discharging [A. Kupczyk's study]

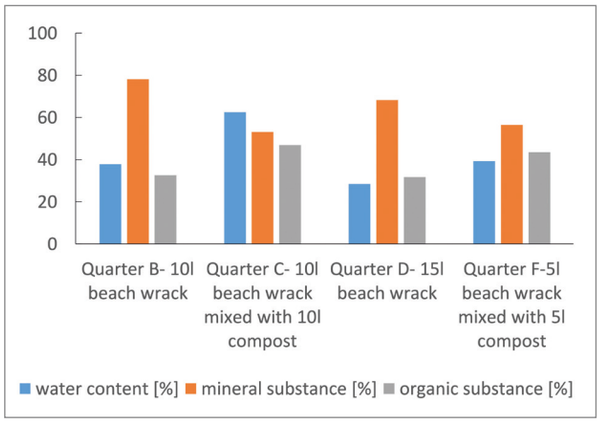


Figure 6.16. Changes in basic parameters in material discharged in RBS after one month of treatment (average value from 3 months) [A. Kupczyk's study]

processed in the system, may require significant space, which entails the financial problem of purchasing land for the construction of the facility.
Another problematic aspect may be the location, which should be relatively close to the beach wrack collecting point. This material contains significant amounts of water, which increase mass and volume, and therefore transportation costs. For this reason, a neighbourhood of the beaches should be considered as a construction site for a reed bed system.
Another problem may be a manmade waste, including plastics found in the collected beach wrack material. Using a reed bed system for beach wrack processing assumes high-quality fertiliser production, and wastes are not a desirable component of fertilisers. There is a pre-selection problem that must be carried out before serving the beach wrack on the bed.

6.8 Administrative/legal obstacles

The definition of "beach wrack" currently does not exist in the European Union legal system. Therefore, it should rely on the "composition of beach wrack" and similar existing definitions. The nearest term for beach wrack in Poland is "kidzina".

Council Directive 92/43 / EEC of 21 May 1992 on the protection of natural habitats and wild fauna and flora prohibits the destruction of the natural environment of "kidzina" on the seashore [Armknecht et al., 2020]. However, according to the European Union Directive on the bathing water quality (2006/7 /EC), the beach management authorities are responsible for removing macroalgae accumulating on the coast [Kupczyk et al., 2019]. Entities responsible for beach management choose cleaning companies, without distinction for what happens with the collected material. They only indicate that it is to comply with the law. This contributes to the inefficient use of beach wrack material [Armknecht et al., 2020]. Following with Directive of the European Parliament and of the Council (EU) 2018/850, the algae is biodegradable waste. It is prohibited to store this kind of material at landfills, so they must be disposed of [Kupczyk et al., 2019]. The Act of 27 April 2001 – Environmental Protection Law (Journal of Laws of 2019, item 1396, as amended)

	PH	COD	TN	TP	N-NO2-	N-NO3-	N-NH4+	PO43-
	[-]	[mg 02/l]	[mg TN/l]	[mg TP/l]	[mg NO2/l]	[mg NO3/l]	[mg NH4/l]	[mg PO4/l]
RW before supplying of BW	8.06	161.00	47.10	0.56	0.08	29.80	0.07	0.32
RW after BW supplying	8.01	258.00	91.40	0.89	0.13	54.80	0.35	0.46
RW after months of supplying	7.85	816.00	40.10	0.36	0.51	12.60	0.57	0.25
Sea water	8.07	81.00	3.69	0.56	0.01	0.15	0.04	0.31

Table 6.2. The quality of reject water (RW) and its change after the supply of fresh material of beach wrack (BW) to deposit

gives consent for "disposing of waste to inland waterways surface and underground waters, internal marine waters or territorial sea waters." for a much higher fee than for storing waste at a landfill [Armknecht et al., 2020].

6.9 Proposals for potential solutions basing strongly on the case study

The reed bed system solution is an option that can be used by local authorities responsible for beach management. It's also a potential idea for companies, which take part in beach cleaning.

Besides, this solution fits in assumptions of a circular economy and change beach wrack into a resource (fertiliser). This gives the possibility of reintroducing nutrients into the matter cycle and allows reusing these compounds in a place where they are desirable. The reed bed system is an environmental solution. As mentioned above, its operation is based on natural processes without introducing new substances to the environment. This solution has a low carbon and water footprint. Both aerobic and anaerobic processes in the reed bed system contribute to forming carbon dioxide (product of oxygen processes) and methane (product of anaerobic processes). 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.

6.10 Conclusions

Results of contamination analysis show that concentrations of some pollutants, like metals or organic compounds in the beach wrack, can affect the environment. The preliminary results suggest that beach wrack can be a source of zinc and chromium to the coastal environment. Moreover, specific conditions, like low oxygen concentration and high redox potential, can foster the release of contaminants from beach wrack (BPA). Preliminary results also show that beach wrack conditions can initiate a transformation of some elements, e.g. mercury (Hg) to more toxic compounds like methylmercury (MeHg).

Regarding the contaminants in the beachcast, in most places, concentrations are below thresholds preventing their commercial use. However, local hotspots appear to exist in the case of some compounds, i.e. cadmium in seagrass in Gotland. This phenomenon may restrict some utilisation options, but not all, in particular regions. Therefore, specific case studies are required in some regions, especially those known to have former historic contamination.

The reed bed system seems to be a potential solution in the case of beach wrack nuisance, enabling its conversion into a resource of fertiliser. The reed bed system allows for significant dewatering and stabilisation of beach wrack. The dewatering process is indicated by changes in the dry matter content in the material processed in the bed.

Beach wrack material is a source of nutrients for reed and positively affects its growth, indicating

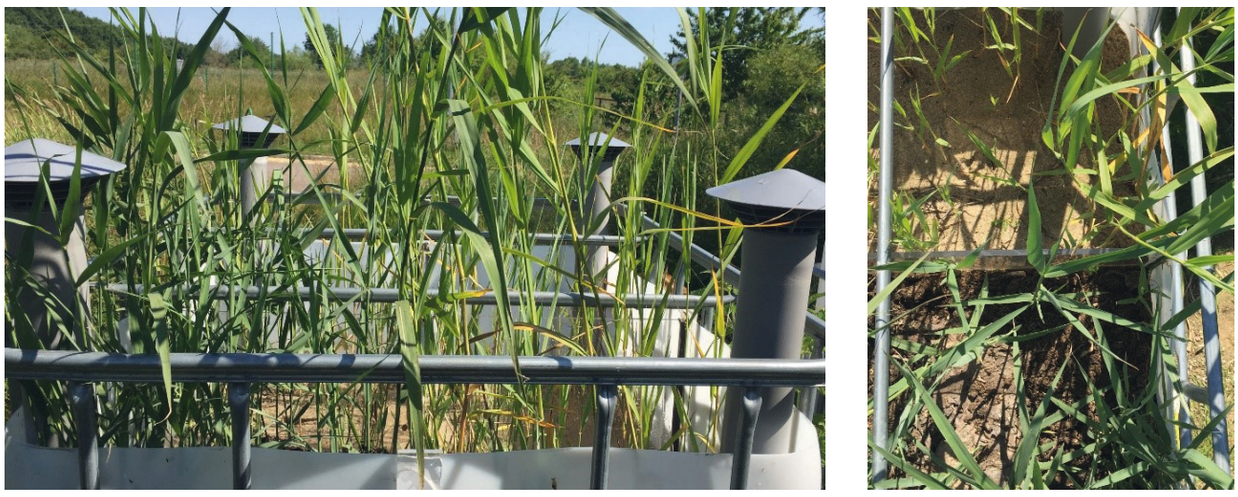


Figure 6.17. Differences in the condition of reed fed with beach wrack material (a) and not fed (b).

good fertilising properties. Between quarters where it was delivered and the "empty" one (there is a significant difference in reed condition (→ Fig. 6.17).

Also, the reed bed system 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 supporters the processes. This solution requires no energy outlays and is characterised by low emission. This fact is an additional advantage of using this solution.

As for the economic aspect of the reed beds, it seems beneficial. The construction of the system does not require large financial outlays due to the simple construction of the facility. When it comes to operating costs, they are also low. Well designed and precisely made reed bed system does not show a high failure. Moreover, no additional chemicals are used, which also reduces the exploitation costs of the system. A potential additional advantage of using the reed bed system for beach wrack processing can be the production of highly nutritious fertiliser, which can become a source of income for the investor.

The transportation of beach wrack material may produce a high cost. If beach wrack is processed far away from the place of collecting, this solution may simply turn out unprofitable. The high water content increases the volume and mass of the collected material, and they are basic factors determining transport costs. The high cost may also be conditioned by the purchase of an appropriate area for the facility's construction.

The use of a reed bed system can also bring benefits to local communities. The first one will be "clean" beaches that tourists will preferably visit. Coastal resorts are struggling with the problem generated by the beach wrack decomposed on the shores – an unpleasant smell and an aesthetic look. Finding the suitable management options and refining the regulations in this matter can contribute to greater interest in given places by tourists, which translates into the profits of the inhabitants who mainly earn on tourism.

Currently, decisions are based on experience from processed sewage sludge, whose properties are well studied. In terms of beach wrack, everything is new. It needs to develop a method from scratch, based on properties and observation of beach wrack material behaviour in the deposit, which is not a simple task.

The main uncertainty of the proposed solution is the end product, i.e. a fertiliser. It's not known, whether its properties meet legal requirements and whether it can be used.

Estonian experience: production of furcellaran both from trawled and beached algae *Furcellaria lumbricalis*



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Location of the study area: Estonia

There is no specific case study in Estonia within the CONTRA project. This chapter presents the Estonian experience related to beach wrack use. It summarises the information regarding the management of rare red algal community (*Furcellaria lumbricalis* and *Coccotylus truncates*) located in the West Estonian Archipelago Sea, Estonia, Baltic Sea. The raw material is collected both via trawling and collection of beached algae and from that furcellaran – an anionic partly sulphated polysaccharide (classified together with carrageenan (E407)) – is produced by the local company Est-Agar AS (www.estagar.ee). Currently studies are carried out to estimate the possibility of also producing R-phycoerythrin (pigment used in the food and biotechnological sectors).

7.1 Location and geographical description

The West Estonian Archipelago Sea (in Estonian: Väinameri) is located in the eastern part of the Baltic Sea in the coastal waters of Estonia (→ Fig. 7.1). It is a hydrologically very active water basin formed by a system of straits connecting the waters of the Gulf of Riga to the Baltic proper and the entrance to the Gulf of Finland. The total surface area of the system is 2,243 km², and the total volume amounts to 10.6 km³ [Suursaar et al.,1998]. This sea area is characterised by its shallow waters: the mean depth of the whole system is less than 10 m with the deepest location at 22 m in the middle of the Suur Strait (between Muhu island and mainland). The salinity varies between 6 and 7 PSU. Sand and sandy clay substrates prevail in the area, harder substrates as gravel or boulders can be found only in the most shallow and wave-exposed areas. Due to the shallowness and the bottom substrate being dominated by fine sediment fractions, water transparency is often very poor. After storm events, the Secchi depth may decrease to 0.5 m, while in the case of prolonged calm weather conditions the photic zone reaches the bottom in about 90 % of this area [Martin et al., 2006, Kotta et al., 2008].

Drifting mats of *Furcellaria lumbricalis* and *Coccotylus truncates* cover soft sediments at depths

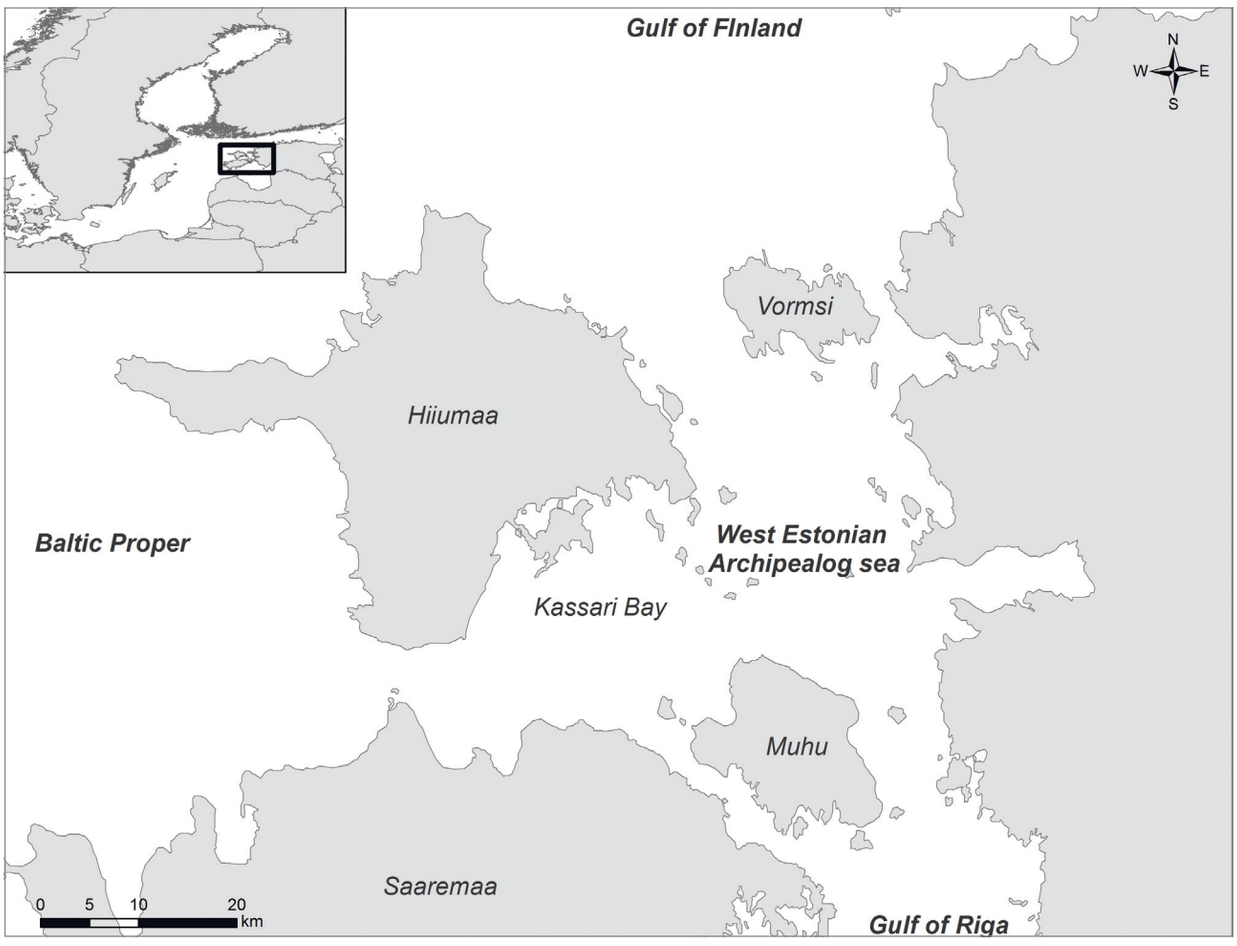


Figure 7.1: Location of the case-study area.

between 5 and 9 m in the subregion Kassari Bay, the community is maintained by the prevailing circular currents and the ring of islets that surround the area [Martin, 2000, Kotta et al., 2008] (→ Fig. 7.2). Similar communities were also present in the waters of Denmark and Poland but were lost due to overexploitation and eutrophication in the period 1970–1980 [Weinberg et al., 2019, Schramm, 1998].

7.2 Description of beach wrack effect as a natural process

In the West Estonian Archipelago Sea, the area of loose-lying algal community has varied within 130-200 km², and the biomass has been estimated between 160 000–260 000 tons in wet weight (in the last 20 years) [Weinberger et al., 2019] (→ Fig. 7.3). The algal mat's average coverage is 70 %, and thickness varies between 5–15 cm. Within the last decade, the areal coverage and biomass values have been relatively stable, around 175 000 km² and 170 000 tons in wet weight, accordingly [Weinberger et al., 2019; Paalme, 2019]. In 2015–2020 the catch suggestions for bottom trawling was 2,000 tons of algae (all species included) in wet weight – representing about 1–2 % of the standing stock [Paalme, 2015, 2017, 2019]. The trawled seaweed contains an average maximum of 8 % additives. In 2019 the number of algae collected via trawling in June and September was 60 tons (https://www.agri.ee/et/eesmargid-tegevused/kalamajandus-ja-kutseline-kalapuuk/puugiandmed). The trawling takes place mostly in the period April-June.

The amount of algae lost via beach cast is estimated at 4,800 tons of wet weight [Kersen&Martin, 2007]. The beached material, both attached and unattached forms of *F. lumbricalis*, is also collected by locals, dried in the sun, and sold to the company. The weather conditions vary a lot annually, but usually, the algae are washed ashore during autumn storms, after which the algae is collected and laid on the fields for wintering. In spring- and summertime the algae is dried in the sun (as hay), compressed into bales, and transported to the company. The company Est-Agar AS takes samples to estimate the share of *F. lumbricalis* within the dried algae; the preferred share is over 80 % (the cleaner

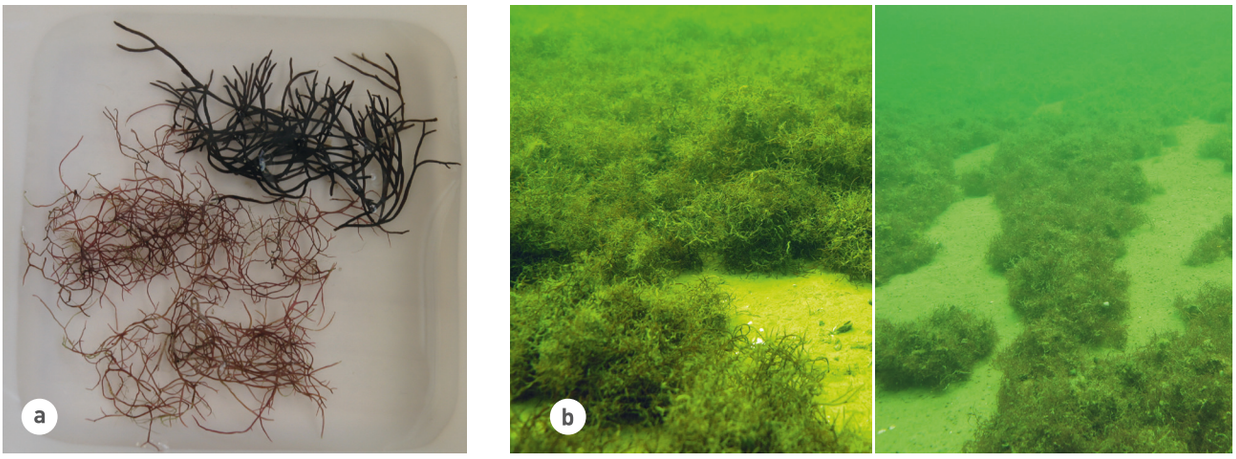


Figure 7.2: Dominating algal species in the Kassari Bay loose-lying algal community (a): A – *Furcellaria lumbricalis*, B – *Coccotylus truncates* (re-drawn from [Paalme, 2017)]; loose-lying algal community in the Kassari Bay (b), closer look (Photo: G. Martin).

material is indeed preferred). In 2020 the company bought in a total of 300 tons of sun-dried *F. lumbricalis*. The price for 1 ton has been fixed at 350 EUR (VAT not included) in the latest years, and some families have gathered the beached algae for several generations. At the moment, there are about 20-30 people who actively collect the beached material across Saaremaa.

7.3 Why beach wrack is a problem?

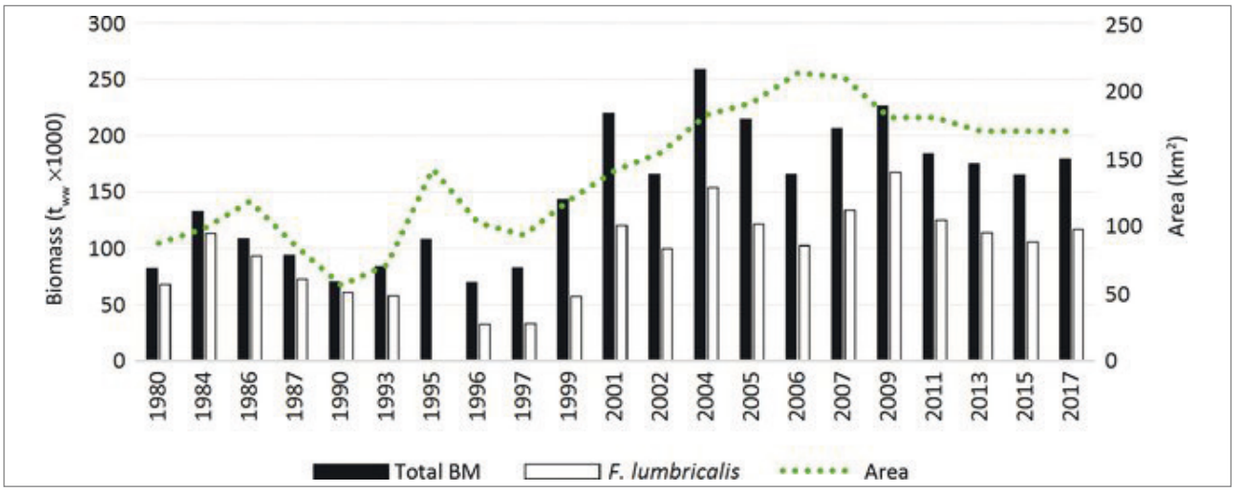
The beach wrack itself is not a problem at the coast of the West Estonian Archipelago Sea, as there are no long and sandy beaches that would be of tourism interest and addressed to beach cleaning. Due to the Kassari Bay's specific conditions, the primary beached algae are *F. lumbricalis* and *C. truncates*, and the beach wrack is seen as a resource and option. The use of beached algae helps to optimise trawling activities and keep the resource to remain its natural reproduction rate.

7.4 Technology recommended

Gathered material is dried and stored having a maximum of 22% moisture content. It is kept in storehouses until further use. Furcellaran is extracted from raw seaweed *F. lumbricalis*, and the liquid extract is purified by filtration. The liquid extract may be converted into flaky furcellaran by evaporation of water to yield by drum drying. Proper release of the dried material from the dryer roll requires adding a small amount of roll-stripping agents (food oil). (Estagar 2020) (→ Fig. 7.4). For the production of 1 kg of furcellaran it roughly takes 20 kg of dried *F. lumbricalis.*

Also, the furcellaran can be isolated from the liquid extract by precipitation of the furcellaran with

Figure 7.3: Interannual variation (1980–2017) of the total community biomass (BM), the total Furcellarialumbricalis biomass, and the area of the loose-lying red algal community in the Kassari Bay, West Estonian Archipelago Sea (re-drawn from [Weinberger et al., 2019]).



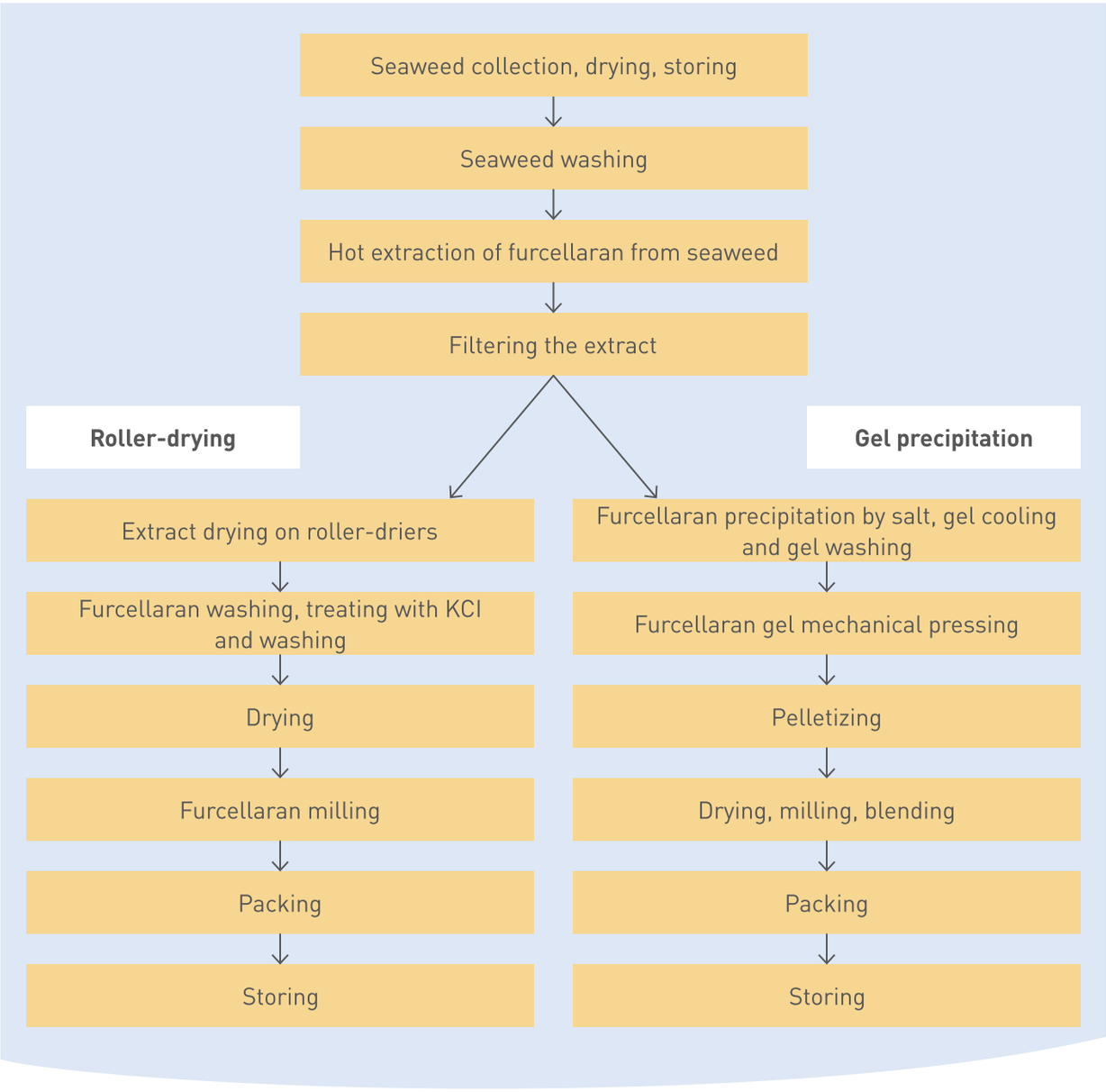


Figure 7.4: Manufacturing options of raw material (re-drawn from [Estagar, 2020])

potassium chloride. This process gives a pure and concentrated product. (Estagar 2020) (→ Fig. 7.4). The growing interest towards the furcellaran and late, the red pigment R-phycoerythrin that can be extracted from red algae, e.g. *F. lumbricalis*, and *Ceramium tenuicorne* [Tuvikene&Robal, 2015b, Kersen et al., 2017] has brought more interest to the land-based cultivation systems. One of the cultivation methods was tested under the project "Development, testing and evaluation of intensive cultivation technology for production of an unattached form of *Furcellaria lumbricalis*" (07/2017 – 31/12/2019, funded by European Maritime and Fisheries Fund) which gave valuable input for the species biology, and cultivation technology can be developed further to meet the suitable conditions for algae [Paalme, 2020].

7.5 Management-related aspects/obstacles

The company Est-Agar AS has been working for quite some years already and has overcome most of the obstacles during its everyday activities. Updating the technology, machinery, and discovering new possibilities for extracting more substances from algae are directing the company's progress at the moment.

7.6 Administrative and legal aspects/ obstacles

In Estonia, the community of *F. lumbricalis* and *C.*

truncates has been harvested via bottom trawling since 1966 and beach cast collections since 1976 together with official regulation on a national level and regular monitoring of the status of the resource [Martin et al., 1996]. According to the Estonian Fishing Act (2016), the *F. lumbricalis* in the sea is in the ownership of the state, and *F. lumbricalis* washed ashore is in the ownership of the owner of the immovable property located on the shore. Regular monitoring is carried out in the period of July-August (end of active vegetation period of dominating algae) and biomass, coverage, and share of *F. lumbricalis* compared to other dominating species (*Coccotylus truncates*), other macroalgal and zoobenthos species are estimated [e.g. Paalme et al., 2017]. Based on the monitoring results, the suggestions for catchment amounts and regions are given. Since 2007 the monitoring of the status of the algal community has been carried out once in 2 years, and the catchment suggestions are also given for a maximum of two years.

With the growing need for furcellaran and R-phycoerythrin, the company Est-Agar AS also plans to start growing algae on its own, and this is where the legislation is missing at the moment, and it's being worked out.

7.7 Proposals for potential solutions

Close contact with research institutes and policy-makers is suggested. The company Est-Agar AS has been involved in working out legislation for farming and the cultivation of algal species in Estonia since 2018.

7.8 Conclusions

Some of the key messages regarding the experience with *F. lumbricalis* harvesting (both trawling and collection of beach wrack) and management in Estonia are:

- the need for official regulation of the algal material (resource) on the national level. *F. lumbricalis* is so far the only separately legislated algae in Estonia, and according to the Estonian Fishing Act the *F. lumbricalis* in the sea is in the ownership of the state, and *F. lumbricalis* washed ashore is in the ownership of the owner of the immovable property located on the shore;
- the need for regular monitoring of the status of the algal community/resource – depending on the interests, but annual/biannual monitoring would be suggested. Due to trawling activities, it is most crucial to estimate the status of the algae and adjust catchment accordingly as the species are also vulnerable to changes in hydrological conditions;
- care for sustainable management on an enterprise level and close contact with research institutions. Through times, there has been one company that has been in charge of catching and producing the *F. lumbricalis*, and they have managed the resource responsively;
- algae cultivation is one possible solution to maintain a continuous flow of the raw material.

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Beach wrack in a business environment: Guidance and inspiration towards increased resource utilization based on innovative treatment options

By J. Almqvist[1], T. Bretz[1], Å., Fondahn, J. Woelfel[2]

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Summary

Beach wrack is a challenge across the Baltic Sea Region (BSR). This report defines the challenges and current practices connected with beach wrack management based on the findings in the CONTRA project. The report also explores new and innovative ways of creating environmental, social and economic value through developed beach wrack practices. It explores the scope of values that can be unlocked by introducing novel ideas. Such novel ideas are the treatment options that were pilot-tested by the CONRA partnership. In this report, the treatment options are compared and evaluated for their ability to generate value and we conclude that they have the properties to unlock both environmental value and monetary value. Furthermore, the report shows that beach wrack management could be improved throughout the BSR by implementing a holistic collect and utilize mindset which takes several aspects of value into account simultaneously. We conclude that the shift from the current remove and dispose practice towards a collect and utilize mindset requires fundamental rethinking and redesigning of how beach wrack is perceived and handled. This shift should be based on the latest research and novel ideas. Suggestions and inspiration for how such a shift might be accomplished are presented in the form of business models and value chains in the last section of the report. We hope it will serve as inspiration and guidance for beach wrack stakeholders in the BSR.



photo: © J. Hofmann

Introduction

About the author

The report at hand has been produced by Krinova Incubator & Science Park in Kristianstad, Sweden as output from the CONTRA project. Krinova stimulates novel thinking and creates jobs and growth. We do this by transforming societal challenges into innovation projects, bringing companies, the public sector and academia together in collaborations that result in long-term and sustainable development.

Krinova is a meeting place for people and ideas, and offers innovation and development support to companies – ranging from the idea stage to established companies. Within the profile area food – environment – health, Krinova creates partnerships and projects at the regional, national and international level. Krinova is one of the 65 members of the national association Swedish Incubators & Science Parks (SISP).

Krinova's role in the CONTRA project

The CONTRA project was structured into four main work packages, each covering the beach wrack challenge from separate perspectives. Krinova's main task was to lead the work on possible business opportunities within the field of beach wrack and sustainability – with special attention given to the innovative techniques researched in parallel by the project partners. During the project, Krinova introduced the project partners to hands-on business development with a focus on aligning the case study treatment options with potential business opportunities. Most of the work was done in a collaborative fashion. The results of these joint efforts will be manifested in this report.

Over the course of the project, Krinova has actively promoted knowledge sharing by utilizing our experience as drivers of open innovation. This was expressed in several interdisciplinary and interregional activities, such as a series of *thematic focus groups* and a *Think Tank on beach wrack and business*. The aim of the focus groups was to share knowledge and cross-pollinate efforts in the South Baltic region. The aim of the Think Tank was to unlock the expertise found in the research community and fast-forward the development of a common approach to beach wrack. Further, Krinova – assisted by members of the partnership – produced a *Transnational Networking Event on the topic: beach wrack in the bioeconomy*, to which more than 50 attendees from more than 10 countries rallied. The results of these activities are a fundamental part of the research which this report builds on.

To summarize, Krinova has engaged in active efforts to drive and develop new ideas and business in beach wrack. The above-mentioned efforts as well as interviews with key experts, partner output reports, literature studies and reading of legacy project reports related to beach wrack lay the foundation for this report.

How to read this report

CONTRA is an acronym for "Conversion of a Nuisance To a Resource and Asset", which signals the intention to facilitate a shift from the current situation to a new scenario where beach wrack has been transformed into a resource. The aim of this report is to offer insights, guidance and inspiration which facilitates such a transition.

We target stakeholders such as policy makers, municipalities, waste management companies, researchers and beach wrack entrepreneurs who wish to explore and implement new and innovative ways of creating environmental, social and economic value through developed beach wrack practices.

This report is divided into three main sections:

- The first section offers brief insight into the current state of beach wrack practices and the beach wrack industry, and evolves into an elaboration on value and change drivers.
- The second section brings focus to the CONTRA case studies and the treatment options that were researched, with an introduction that is followed by a comparison of the options based mainly on environmental and economic perspectives.
- The third section takes on a guidance and implementation perspective in which suggested business models are introduced.



Photo I On-site pre-processing of beach wrack, photo: Hanseatische Umwelt CAM GmbH.

Introduction to the beach wrack challenge

Beach wrack is a term applied to organic material washed ashore due to wind, waves, and tides. It is neither algae nor sea grass, but a mixture of many things, including different algae and sea grass. Beach wrack is a largely unpredictable and nonhomogeneous material which inevitably mixes with litter and sand as it lands on a beach. As the Baltic Sea Region (BSR) is a microtidal area, landed beach wrack material can cover the coastlines for weeks. When the material covers beaches and decomposes, it affects the attractiveness of the surroundings, e.g. a bad smell covers the area, bathing water is less accessible, and algae bloom due to accumulation of nutrients. Beach wrack is therefore a challenge to coastal communities, particularly those whose economies rely on beach tourism. To maintain attractive and functioning beaches, a widespread practice of removal and disposal of beach wrack has been established in the BSR. It is common for stakeholders such as municipalities or non-profit organisations to bear the responsibility of both management efforts and expenses (CONTRA reports of Möller et al., 2021 and Hofmann et al., 2021).

There is no available data on the total amount of removed material throughout the BSR, but a yearly collection potential of up to 500 tonnes/km was presented by the Bucefalos project. This estimate was based on sandy beaches in the Skåne region in southern Sweden (Hvitlock, 2014). Historically (and still today to some extent), the material has been used by farmers as a fertilizer. However, most of the material is removed from the beaches and disposed of in landfills or back into in the sea (Mossbauer et al., 2012, CONTRA-report Hofmann et al., 2021). This practice can be questioned from both an environmental and a resource perspective. Over the last decades, efforts have been made to understand the material and its potentially valuable properties, as well as ways of utilizing those properties. But the notion of beach wrack as a valuable resource in a greater economic perspective is still new and driven mainly by publicly-funded initiatives rather than market forces.

There is a common misunderstanding that beach wrack can be used for high-value applications such as food, cosmetic or pharmaceutical in the same way pure/fresh algae can. The reality is that beach

wrack is a complex material with several inherent properties hindering its utilization:

- **The sand content,** which can amount to as much as 90 % of the dry weight if it is not processed. Sand (and water) is heavy and does not transport well. Furthermore, sand can be a limiting factor in relation to processing options.
- **The unpredictability of material.** Given the nature of beach wrack, it is neither possible to forecast the available material nor its quality.
- **The potential content of heavy metals.** In Germany, beach wrack material is classified as waste by national legislators in Germany. Other countries in the BSR do not offer as distinctive legal guidance, which is a source of uncertainty to beach wrack stakeholders.

The focus of most beach wrack management nowadays is removing and disposing of the material with as little effort and cost as possible, with the sole aim of offering enjoyable beach experiences. This style of management does not take potential values associated with environmental impact or the materials inherent properties into account. **The CONTRA project aims to research and, if possible, facilitate a shift from the current situation to a new scenario where beach wrack management is based on research, circular models and innovative ways of utilizing the material in value-adding processes.**

The resource-oriented solutions today

In the BSR, there are only a hand full of organizations operating with beach wrack as a core resource. The industry is focused on resource utilization in established processes, such as controlled composting and anaerobe digestion, where it is mixed with other resources with a "waste label" such as "green waste".

Hanseatische Umwelt CAM GmbH can be considered forerunners in the beach wrack industry. The company operates a waste management site in northern Germany and produces a soil improvement product made from beach wrack and "green waste". The company sources beach wrack from the coastline around Rostock in northern Germany and transforms it into a soil improvement product through a controlled and research-based composting process. The product has its own brand, and the product is sold in consumer-sized boxes for home and gardening applications.

Solröd Biogas in Denmark is a biogas plant owned by the municipality of Solröd which utilizes beach wrack as a component in anaerobic digestion. They utilize beach wrack in combination with other substrates in their process. The plant is owned by the public and services its local industries with heat and energy (https://solrodbiogas.dk/solroed-biogas-fortsaetter-succesen/).

A handful of companies in Denmark, Estonia and Germany operate based on pure algae and seagrass such as eel grass (Zostera marina) for use as natural building, insulation, and stuffing material and red macroalgae or seaweed (Furcellaria lumbricalis), which is used to extract furcellaran, a gelling agent in food applications. However, beach wrack is complex, thus the collected material is never pure. These applications are therefore based on either extensive cleaning of the material or on harvesting the material (a) before it is washed ashore or (b) on special occasions when it is washed ashore as a single component. These applications do not address the need of handling large amounts of beach wrack material.

> "The collected material contains a number of components that could be extracted (e.g. Furcellaran as a gelling agent). The outlook for doing so depends to a high degree of the quality of the collected material, which varies based on timing and beach management practices. Some components, such as sand, algae, eelgrass, wood, are accessible through mechanical sorting, while some components could theoretically be made available through more advanced processing. In the latter case, there are uncertainties regarding the legality as well as the feasibility.
>
> Results from CONTRA Think Tank

What is driving change?

This section identifies factors which have the potential to drive change in the beach wrack sector.

Legality

Municipalities and private beach operators invest EUR 20–40/meter in beach cleaning efforts (CONTRA report Hofmann et al., 2021). These efforts are generally driven by the will to offer beach experiences with little or no beach wrack, but in some instances also by legal regulations, such as EU Directive (2006/7/EC which regulates responsibility for bathing water quality (CONTRA-Position paper Chubarenko et al., 2021). Costs associated with removal of beach wrack vary depending on how much material needs to be removed, whereas costs associated with disposal vary across the BSR region depending on which laws are in place and how local legislators interpret these laws. For example, waste management companies in northern Germany charge a handling fee of EUR 50–70/tonne of material for the service of properly disposing the material in accordance with laws and regulations, whereas municipalities in Sweden have no requirements of upcycling, resulting in no-cost practices such as disposal into the sea.

- If beach wrack is established as a resource in the bioeconomy, it is likely that legislators across the BSR will avoid giving out exemptions for direct disposal of beach wrack material. In this scenario, municipalities become legally bound to turn towards resource-oriented beach wrack management.
- If municipalities are legally bound to turn towards resource-oriented beach wrack management, the cost for disposal of the material will initially be higher due to costs associated with recycling.
- If the demand for recycling of beach wrack material is higher and sustainable business models are built based on the material, it is likely that the costs associated with recycling will decrease over time.

For more information on legislation related to beach wrack management and its challenges please read the following two documents CONTRA-Legal framework document and CONTRA-Legislation list.

Economy and Tourism

Coastal and maritime tourism is of importance to coastal municipalities and to local coastal economies in general. The EU *Blue Economy Report* states that coastal and maritime tourism is the largest sector in the blue economy, accounting for over 50 % of the job opportunities and 36 % of the GVA (Gross Value Added) (European Commission, 2019). Further, it is identified as a sector with high potential for sustainable jobs and growth. Recent growth rates in the BSR blue economy sector are above the EU growth average (CONTRA-report Hofmann et al., 2021, European Commission, 2014a).

In the BSR, the sandy beaches along the Baltic coast allow their surrounding communities to generate an important share of their economic revenue from tourism and recreation. Germany, Poland and Russia were named in the World Tourism Organizations list of top 10 destination countries globally. Unlike most European large tourist markets, the BSR has a very high share of domestic and intra-BSR tourists. Between 2014 and 2016, direct employment in the BSR tourism industry increased by 6.5 % to a total of more than 650,000 jobs directly provided. The major labour markets are the German Baltic Sea coast, with more than 180,000 employees, closely followed by Sweden, with 173,000 employees in the tourism industry (CONTRA-report Hofmann et al., 2021). According to the European Commission, tourism can be a significant economic component in many EU regions, especially in remote/peripheral regions, including coastal and outermost ones such as the BSR. (CONTRA-report Hofmann et al., 2021, European Commission, 2014b).

Beach quality as a driver of tourism

Travel for holidays, recreation and other forms of leisure accounted for just over half of all international tourist arrivals in 2016. Beaches is one of the main interests to these travellers (Giorgio et al., 2018). The perceived beach quality of a destination could arguably be considered a key factor in the prosperity of a tourist region. But how do tourists assess beach quality? Giorgio et al. (2018) refers to the "Big

Five" factors: safety, facilities, water quality, no litter and scenery. On a general level, it can be argued that the presence of beach wrack affects all five of these factors. But how is beach wrack perceived by beachgoers? According to a study conducted by CONTRA partners (CONTRA report Hofmann et al., 2021) via public surveys, 55% of the respondents perceived beach wrack as dirty or sometimes dirty and more than 60% of the respondents perceived beach wrack on the beach or in the water as negative or largely negative to their beach experience. A study by Risén et al. (2016) found "a significant increase in the stated visiting frequency when respondents were given the option of an algae-free beach". Further, Risén et al. (2016) argues that improved beach quality will attract higher visiting frequencies from inhabitants as well as beach tourists travelling for holidays or day trips.

- Beaches without beach wrack are perceived as more attractive.
- Removal of beach wrack adds properties that are of value to residents and beachgoers.
- Attractive beaches are a key factor when tourists plan their vacation.

The monetary value of a clean beach

Risén et al. (2016) made an effort to calculate the willingness to pay (WTP) amongst inhabitants in a Swedish coastal municipality (Trelleborg). Respondents were asked to state how much they would be willing to pay for a set of different beach cleaning programmes. The study reached the conclusion that respondents "displayed a considerable mean willingness to pay". For the largest programme presented, respondents were willing to pay EUR 54 in annual fees. In the same study it was presented that non-local beach visitors would generate approximately another EUR 54/inhabitant (Risén et al., 2016). This calculation is based on a 10% increase in the municipalities' total tourism sector caused by the increased beach attractiveness. Thus, the sum of value created by beach cleaning efforts in this particular municipality is just over EUR 100/inhabitant. Applying this logic to a municipality of 40,000 inhabitants generates a value of EUR 4 million. For reference, Kristianstad Municipality with 40,000 inhabitants spent no more than EUR 100,000 EUR on average between 2015 and 2018 based on 2.5 km of managed beach. This is an indication that the value (monetary) invested by municipalities is far less than the value (total) it creates.

> **"Beach cleaning adds value to the beach experience depending on the location, the beach and community expectations of the beach as a recreational space. Each beach is different, and there are many variables. We can talk about economic revenue from beach tourism (national level and in some cases county level). Bathing water quality (healthy/not healthy) has significant impact on the establishment of tourism based on water activities.**
>
> Results from the CONTRA Think Tank

- The value of a clean beach can be expressed in financial terms.
- It is likely that programmes aimed at cleaning beaches and keeping them attractive are a good investment from an economic standpoint.
- Costs associated with beach cleaning can logically be funded through both tax from inhabitants and revenue from tourism.

Environmental value

The environmental discourse on beach wrack management in relation to the health of the Baltic Sea is focused around two main questions.

- The first question is whether beach wrack can be collected (or even harvested) without causing disproportionate damage to the (marine/beach) ecosystem.
- The second question is whether the collection and sustainable treatment of beach wrack material can offer environmental value compared to the material's natural life cycle.

The perspective offered in this report isolates the collection and treatment of beach wrack material from the question of whether removal of beach wrack is justified from an ecological perspective. For a more detailed overview of the ecological aspects of beach wrack management, please refer to the two CONTRA-reports of Möller et al. (2021).

> **“There is reason to believe that big piles of beach wrack, such as those commonly found on managed beaches, will emit significant amounts of methane because of the anaerobic process. There is also evidence that the decomposition process of naturally-occurring assemblage of beach wrack cast to the shores will limit the amount of oxygen, preventing the development of possible animal organisms that are there. Decomposition processes, or decay processes, also disrupt the functioning of the sediment directly under the organic material layer.**
>
> Results from the CONTRA Think Tank

The Baltic Sea

As an almost landlocked inland shallow sea, the Baltic Sea has always been exposed to particularly high loads of nutrients due to the many rivers flowing into it and the low exchange with other seas. Due to the increasing human settlement of the catchment areas, this influence has increased over the centuries. Consequently, the Baltic Sea in particular is facing several challenges that impact the functioning of its ecosystem, e.g. eutrophication, hazardous substances, non-indigenous species, seabed loss and disturbance, overfishing, etc. Reducing eutrophication of the Baltic Sea is continuously one of the biggest challenges. It is estimated that over 97% of the Baltic Sea area suffers from eutrophication due to past and present excessive inputs of nitrogen and phosphorus. There has been a decrease in the inputs of nitrogen and phosphorus to the Baltic Sea sub-basins over the years, but agriculture still plays the key role in nutrient pollution (HELCOM 2018a). Contamination with hazardous substances is another great concern – thousands of environmentally hazardous substances have been identified as potentially occurring in the Baltic Sea and up to one-fifth of those are being monitored regularly. The whole marine environment in all parts of the Baltic Sea is impacted by hazardous substances. Among others, the contamination level of mercury, polybrominated diphenyl ethers (PBDEs), and the radioactive isotope cesium-137 is particularly high (HELCOM, 2018b).

The decomposition of beach wrack

After beach wrack is deposited on the beaches, a microbial decomposition process starts and nutrients, sulphur dioxide (responsible for the bad smell), and greenhouse gases (GHG) such as carbon dioxide and methane are produced. The decomposition process is directly dependent on temperature, species composition of the beach wrack and the infauna/bacteria living in it as well as the amount of sand it is mixed with. In summer, the emission of GHG is likely high due to rising temperatures and the dominance of annual species of macroalgae, for example brown filamentous algae (*Pylaiella littoralis* and *Ectocarpus siliculosus*), which are easily degradable. Beach cleaning with tractors can contribute to mechanical breakage of the biomass and an increased sand share – these two factors decrease the decomposition rate. However, roughly 40–50% of the beach wrack is not decomposed. This fraction is usually either buried in the sand (Køge managed beach) transported by winds or storms back to the water or to adjacent areas and/or the back of the beach and used as nutrition by the beach vegetation. Decomposition of beach wrack material can basically be divided in two phases:

- initial decomposition (fast rate), where a finer fractioned and more reactive pool of organic matter is rapidly degraded (this is the source of most GHG emissions).
- second decomposition (slower rate), which is a slow process due to long and structural carbon molecules.

In both situations, the carbon is cycled in one way or another, either as dissolved inorganic carbon in the water by eventual transport to deeper ocean zones, or on the beach by integrating in new on shore plant biomass through photosynthesis. As both algae and higher plants accumulate pollutants from



Photo II Beach management using tractors in Poel, Germany, photo: J. Hofmann

seawater and, to some extent, in the sediments, beach wrack can also be a potential source of environmental contamination. Existing studies show that algae are enriched with heavy metals such as mercury and cadmium (Beldowska et al., 2015, Franzen et al., 2019), especially in comparison to concentrations usually encountered in the sandy beaches. These heavy metals can be released into the surroundings.

- The decomposition process of beach wrack results in negative environmental effects, such as heavy metal release, GHG emissions and eutrophication.
- Reduction of the negative environmental effects associated with decomposing beach wrack can be achieved by disrupting the decomposition process.
- Environmental value can be created through choice of beach wrack management practices.
- Beach wrack material can be used in a circular economy as energy and material input.

“ Emissions of GHG was measured on a 2 ha beach in Køge (Denmark). The results showed annual emissions of up to 57 tonnes of CO equivalents.

(ongoing research by the CONTRA partnership)

Innovative treatment options

A fundamental part of the CONTRA project was the research and pilot testing of new and innovative treatment options in which beach wrack could be utilized. The task was performed by seven research teams associated with research institutions, companies or municipalities in the BSR. The treatment option research could potentially become a fundamental part of future sustainable beach wrack practices. As discussed in the previous chapter, perspectives such as environmental value, tourism and legality are potential drivers of change. Another force that may drive change can be unlocked if treatment options can generate value based on the material and be proven feasible. The following section briefly describes the case studies performed in the CONTRA project, with specific focus on their respective process and value proposition. The case studies are also compared from both an economic and an environmental perspective. For additional technical aspects, please complement the reading with *Case studies for innovative solutions of beach wrack use: Report of the Interreg Project CONTRA* (CONTRA-report Chubarenko et al., 2021), which is referenced in the following section.

Case study 1: Beach wrack-based soil production

It is possible to co-compost beach wrack with terrestrial organic waste, transforming the biomass into soil improvement products. The continuously monitored process of the thermophile composting procedure, with temperatures of up to 70°C, leads to a mature and hygienized compost substrate after 3–6 months. The compost thus meets all regulation requirements and pollution thresholds to offer the product to the market. The end product is a powerful soil improvement product which gets its specific properties from the blue biomass included in the compost. The product-specific features include improved plant and root growth and improved soil quality parameters. The use of composted marine biomass could reduce the application of mineral fertilizer in the coastal agriculture of the Baltic region, thus contributing to a reduction of the nutrient input to the Baltic Sea (Aldag & Staemmler, 2021).

Case study 2: Bio-coal from beach wrack

It is possible to produce bio-coal from beach wrack, thus transforming biomass into energy. By imitating the natural carbonization of biomass, the process (Vapothermal Carbonization) can be completed within hours. The end product is a bio-coal similar to lignite (brown coal) or even hard coal and can be used as a carbon-neutral alternative in processes traditionally using fossil coal (Garrels, 2021).

Case study 3: Beach wrack as a compost material in landfill biocovers

It is possible to use compost made partially from beach wrack to reduce GHG emissions from old landfills. To reduce GHG emissions, the compost is placed on top of the landfill as a "biocover". The methane-oxidizing bacteria in the compost convert methane to CO_2, which is 25 times less potent than methane. The case study showed that beach wrack compost can live up to the standards set for use in a biocover, however more tests are needed to understand how composting processes affect the level of methane-oxidizing bacteria (Guizani et al., 2021).

Case study 4: Assessment of beach wrack applicability for dune restoration measures

It is possible to use beach wrack-based compost in erosion protection measures to promote plant growth and root stability. In areas with eroding dunes, supporting measures can be applied using (a) wooden structures filled with beach wrack and soil on the seaward side of the dune, where sand naturally accumulates, and (b) the compost as a nutrient source for artificially planted greenery on the back side of the dune (Gorbunova et al., 2021).

Case study 5: Baltic beach wrack thermal recovery and relevant analytical performances

Gasification is the thermochemical conversion of organic material by partial oxidation at high temperature into a combustible gas mixture (syngas). The gasification processes involve several stages. Initially, pyrolysis occurs in a reaction producing char, where biomass decomposes in the absence of oxygen. At low temperatures (below 450°C), pyrolysis will mainly yield biochar, while bio-oil is the main product at intermediate temperatures and

gases are produced at high temperatures (greater than 800°C). Controlled by the thermal pyrolysis environment and the final pyrolysis temperature, pyrolysis product includes biochar, bio-oil and gases such as methane, hydrogen, carbon monoxide, and carbon dioxide. Additionally, the gas can be burnt to produce heat or converted into electricity and heat. Conventional biomass gasification processes require dry feedstock (Katrantsiotis et al., 2021).

Case study 6a: Nutrient and pollutant flux to coastal zone originating from decaying algae & plants on beaches

Beach wrack was identified as a vector transporting marine pollution and nutrients to the shallow coastal zone. Even after deposition, it continues to accumulate substances from the seawater. It is therefore possible to assist the clean-up of the Baltic Sea through beach wrack removal. Furthermore, the positive role of beach wrack for beach biota communities was verified to be much smaller than expected due to oxygen consumption by decomposing biological material, thus disrupting the natural process of water purification by filtering through the permeable sediments of sandy beaches and shallow water sediments. This means that the beach wrack could be safely harvested from municipal/tourist beaches without disturbing the ecosystem (Kupczyk et al., 2021).

Case study 6b: Beach wrack treatment in reed bed system

It is possible to utilize the beach wrack material in Reed Bed Systems (RBS). It is currently most used for sewage sludge. The process is low tech and requires low maintenance and low energy input. Its design enables both aerobic and anaerobic conditions. The end product is a soil improvement product which could be used as a fertilizer. A second application possibility could be "land creation", which could be accomplished by positioning the RBS in an area where stabilization is required. Because of its natural look and the odour-free process, the RBS melts into the surroundings and could thus be installed near a beach wrack landing site. Moreover in RBS integrated treatment of reject water created during dewatering and stabilization Beach Wrack is accomplished too thus there is no negative impact on the environment during this kind of treatment (Kupczyk et al., 2021).

Comparing the treatment options

The following section offers a comparison of the CONTRA case studies from an environmental and economic perspective. The comparison can also function as a display of the treatment options' strengths and weaknesses. All data presented in this section was acquired in dialogue with the respective case studies. For further reference, it is important to note that each case study was run in a unique setting (country, type of organization, staff) and represented different approaches to the beach wrack challenge. These circumstances brought a series of case studies that range from early research phase to implementation stage. A particularly important factor is to be familiar with the type of organization behind each effort:

- Case studies 1 and 2 were performed by private companies with an expressed aim of utilizing beach wrack in their respective business models.
- Case study 3 was performed by a municipality in cooperation with a university and could be considered a test bed/pilot effort of new technique in a "live" context.
- Case studies 4, 5 and 6b were research projects performed by research institutions in a small scale in a research context.
- Case study 6a was performed by a research institution but did not research a specific treatment option. Therefore, it is not included in the comparison.

Overview

The case studies were divided into two main sections. The first section (CONTRA treatment options) are options that utilize the material as it is collected, while the second section (Based on composted material) are options that utilize a compost material based on beach wrack. The table shows an overview of the case studies and respective end products, and gives a general idea of how they can

be used. Though data is not represented in → table I, there is an interesting distinction between treatment options that require transportation and options that do not. Case studies 4 and 6b are "on-site installations" where the material is utilized in very close proximity to the landing site, whereas the other options require transportation to a treatment facility.

In relation to capacity, the treatment options show a vast range. As previously mentioned, the case studies were conducted in different scales, which is reflected in the data. Case studies 1 and 2 are calculated on a commercial scale and offer a capacity of several tonnes/day. Case study 5 is based on a lab scale, thus offering significantly lower capacity. Case study 6b is based on a very small unit of 1 m². Case studies 3 and 4 are based on specific installations. It is difficult to scale the data without making assumptions, but going forward we have scaled case study 6b into a 1,000 m² installation which would offer a capacity of 50 tonnes over an 8–10-year period. The capacity offered by the case studies is a key factor in choosing processing options in a site-specific context.

From a legal perspective, much is still unknown regarding beach wrack (CONTRA-Legal aspects and CONTRA-Legislation list). When comparing the case studies, the data on legal aspects is based on the country in which the case study was performed and the known national laws/regulations that regulate the specific process. It should be mentioned that Germany seems to offer a clear legal framework in which beach wrack is regarded as organic waste material.

CONTRA treatment options	End product	Use	% beach wrack share in the process	Assessment of maximum capacity	Process time	Legality/ permits
Case study 1: Controlled Composting (Germany) Company	Compost, compost-based soil substrates	Gardening, agriculture, fertilizer, soil substrate production	30 %	7 tonnes/ day	120 days	Waste treatment plant with permission to treat and store biological waste
Case study 2: Vapothermal Carbonization (Germany) Company	Biochar/ lignite	Energy/heat production, further processing (e.g. for activated carbon)	100 % ideally	25–50 tonnes/day	6 hours	Certified waste management company, approval according to the Federal Emission Control Act in Germany
Case study 5: Gasification (Sweden)	Biogas/ Syngas	Energy/heat production	100 % ideally	200 kg/day (lab scale)	8 hours	No data
Case study 6b: Reed Bed System (Poland) University	Fertilizer, structure-forming material	Land regeneration, on-site environmentally-friendly disposal	50–100 %	50 kg dry matter of beach wrack per m² annually	8–10 years	New technology which is not included in regulations

CONTRA treatment options	End product	Use	% beach wrack share in the process	Assess-ment of maximum capacity	Process time	Legality/ permits
Based on composted material						
Case study 3: Biocover (Denmark) Municipality/ University	Biocover	Compost for GHG mitigation	Mixture with 33 % blue biomass in the compost	100 tonnes	not applicable	Permit needed and compost must be tested for level of pollutants/ heavy metals
Case study 4: Use for coastal defence structures (Russia) University	Greenery of the dunes	Erosion protection	100 % blue biomass compost	1 tonne	not applicable	No

Table I Table showing basic data for the respective treatment options.

Material quality and pre-processing needs

The quality and composition of the collected material affects the treatment processes and the quality of its end product. While the quality of the landed material cannot be controlled
(species, state of decay etc.), efforts can be made to obtain the material in favourable quality. Such efforts include quick collection (avoids decomposition) and mindful collection (avoids unnecessary sand content).

In the CONTRA project, **none of the case studies require specific algae species**. However, case study 5 shows better results using brown algae. In terms of decomposition status, some case studies are affected whereas others are not. Case study 1 indicates that fresh material is favourable in composting processes and highlights that screening/ pre-processing takes less effort when the material is fresh, hence it is a factor for other case studies as well. Sand and water content in the collected beach wrack material is generally significantly higher than what is accepted by the case studies (CONTRA- Position Paper Chubarenko et al., 2021). Case studies 2 and 6b are characterized by acceptance of high sand and water content, whereas case studies 1 and 5 accept water up to 50 % and sand up to 30 %. Even so, it should be highlighted that, while acceptance of high water and sand content may be an advantage in some situations, the processing of sand and water is not the objective of the effort. For all case studies, litter separation is preferable. Hence **all of the displayed solutions require some sort of processing step** (screening) before the material can be utilized. Based on the objective of treating beach wrack material, this step should include measures to handle as little sand and water as possible in the continued process (including transport, etc.). Given these indications, the perspective of material quality and pre-treatment are important factors when implementing measures to improve beach wrack management practices, e.g. by selecting a site-specific treatment option.

CONTRA treatment options	Acceptable water content %	Acceptable sand content %	Acceptable salt content %	Is the decomposition status of collected material a factor for the results?	Need for specific algae species (yes/no)	Litter separation needed
Case study 1: Controlled Composting (Germany) Company	50 %	30 % weight share	1–2	As fresh as possible. Decomposition affects the quality of the raw material and its treatability (Screening)	No	Yes. Usually done close to the beach by means of screening.
Case study 2: Vapothermal Carbonization (Germany) Company	No limit	No limit, less is better for biochar quality	No limit, less is better for biochar quality	Yes, mineralization lowers biochar quality	No	Not for the process, but biochar quality is better with little litter
Case study 5: Gasification (Sweden) University	40–50 %	30 %	0.1 % – less is better for process quality.	Does not matter	Brown algae is preferable because of higher energy value.	Plastic, metal, etc. need to be separated. Organic content can be part of the process.
Case study 6b: Reed Bed System (Poland) University	No requirements	No requirements	No requirements	No	No	Yes
Based on composted material						
Case study 3: Biocover (Denmark) Municipality/ University	For final compost used in biocover, the acceptable water content value is 0.3–0.5 g/g dry weight	Not known, but less is better.	No data	Possibly better if it is less decomposed, as then the organic material will make up more of the volume of the compost.	No, but less eelgrass is better, as it hinders the composting process	Ideally some, but not needed to a fine degree
Case study 4: Use for coastal defence structures (Russia) University	No limits	No limits	No limits (in case of the South Baltic Beach wrack)	Total defragmentation	No (in the case of South Baltic BW)	Yes

Table II Table showing data regarding material quality and pre-processing needs for the respective treatment options.

Environmental comparison

The comparative analysis of the case studies is built around indicators connected to water quality (heavy metal separation and nutrient capture) and indicators connected to climate change/global warming/carbon cycle (GHG mitigation and carbon sequestration). The analysis in → table III compares the case studies to (a) each other (b) common solutions of disposal (push the material back to sea, dispose in landfill) and (c) the natural life cycle of beach wrack.

CONTRA treatment options	Heavy metal separation	Nutrient capture (circular)	GHG mitigation	Carbon sink
Case study 1: Controlled Composting (Germany) Company	No, only a dilution effect by mixing it with terrestrial organic material (green waste)	Long-term organic bond of nutrients during the composting process. Results in less nutrient leaching on fields	Yes, compared to uncontrolled decomposition, which results in CH4 emissions	Probably
Case study 2: Vapothermal Carbonization (Germany) Company	Heavy metals can be found in incineration ash and ash from exhaust gas cleaning. Ash must be landfilled if heavy metal concentration is too high	Maybe, if used for soil improvement. No if used as fuel.	Renewable fuel	Yes, if biochar is built into the ground No if used as fuel
Case study 5: Gasification (Sweden) University	Yes, but mercury release to atmosphere (gas treatment needed)	Removal	Renewable fuel	No
Case study 6b: Reed Bed System (Poland) University	No, but heavy metals are mainly found in stable residual fractions.	Removal	Yes, no methane produced	Probably
Options based on composted material				
Case study 3: Biocover (Denmark) Municipality/ University	Removal from sea to landfill. Compost exceeding limits cannot be utilized as material for Biocover	Yes	Yes	Yes
Case Study 4: Use for coastal defence structures (Russia) University	No	Circular use	Slight mitigation but CH4 is releasing in the process	Carbon neutral/ possible carbon sink in a long-term perspective

Table III Table showing environmental data used in the analysis.

Research from the CONTRA project shows that beach wrack can be a source of **heavy metal release** to the coastal environment. By collecting the material and treating it with techniques researched in case studies 2 and 5, heavy metals are not only removed from the beach environment but also separated and removed from the cycle. Other treatment options, such as those of case studies 1, 3, 4 and 6b, do not offer removal of metals from the cycle. Utilizing the material in controlled composting (case study 1) requires the content of heavy metals to be measured continuously and kept under legal

limits. By processing the material in accordance with the method in case study 6b, heavy metals are mostly found in stable residual fractions and the metals are not available for the plant.

Eutrophication is a known challenge to the BSR, and the negative effects sometimes have a local impact on water quality. Nutrients are released as beach wrack decomposes, which leads to increased levels of nutrients at specific sites potentially causing algae bloom in nearby bathing water. It is likely that collection and removal serve to interrupt this process (CONTRA-report Chubarenko et al., 2021). However more research is needed (CONTRA-reports Möller et al., 2021). All case studies intervene with the natural decomposition process by removing the material, thus contributing to decreased levels of nutrients in beach environments. In case study 4, the removed material is redistributed close to the beach environment in order to aid dune formation, i.e. nutrients are made available for dune vegetation and are bound with the growing higher plants. In case study 1, the nutrient-rich material is used as a resource in controlled composting. This method explicitly aims to utilize the material's nutrient content to produce a high-end soil improvement product. The product is developed for use in gardens and potted plants, thus moving the nutrients from the beach environment, where there is an excess, to an environment where they are needed and bound in higher plants.

Emission of greenhouse gases (GHG) and carbon sink properties were not explicitly researched in the CONTRA project, however researchers in the project suggest that decomposing material (in the water, on the beach, collected in piles) might produce significant GHG emissions (CONTRA-report Möller et al., 2021) The species composition of beach wrack affects the level of decomposition rates, which is related to GHG emission, and carbon cycling, which can be context-dependent, i.e. local and regional environmental circumstances. The carbon sink potential of beach wrack is evaluated by the amount of beach wrack that is not decomposed and is transported by winds and storms to coastal and deep waters, and to adjacent areas and/or the back of the beach. More detailed measures for these factors are therefore needed for calculating carbon budgets and estimating the beach wrack's potential as carbon sink. Collecting and removing the material (interrupting the decomposition process) followed by utilization will offer alternative scenarios as opposed to the material's natural cycle.

CONTRA case studies offer treatment options in which GHG emissions are mitigated. Case studies 1 and 6b are based on controlled composting in which methane is released to a lower degree, thus resulting in less CO_2 equivalents to the atmosphere as opposed to the natural decomposition. The end product from case studies 2 and 5 is renewable biofuels (syngas/lignite), which are so-called carbon neutral fuels. Case study 3 utilizes a compost based on beach wrack to mitigate methane emissions from landfills. Case study 4 aims to aid and stabilize sand dunes which contribute significantly to carbon storage (Beaumont et al., 2014). Further comparison of the treatment options from an eco-system perspective can be found in the two CONTRA-reports of Möller et al. (2021).

Economic comparison

The economic comparison offers initial insights into the economy of the respective case studies. An analysis of the respective **points for break even** and the **expected profitability over time** is presented and adds a new dimension to the feasibility perspective. The point of view of the comparison is a *treatment facility* operating based on the innovative treatment options.

Data analysis – preconditions

All initial data in the analysis was collected from representatives of the case studies. If data was not specific or precise, for example if a range x-y was delivered, the data was reformulated to an average number. If data was delivered in a deviant unit, for example man-hours instead of actual cost, the data was reformulated using common price points. Further, all calculations include a handling fee which was set to EUR 60/tonne. The handling fee is a compensation for accepting material at a recycling facility. Experience in handling fees was derived from the German case studies. The handling fee has significant impact on the outcome of the analysis as it implies that treatment facilities get paid to recycle the material.

CONTRA treatment options	Estimated treatment capacity	Estimated monetary value of end product/tonne treated material	Estimated initial investment cost	Estimated variable cost/tonne treated material
Case study 1: Controlled Composting (Germany) Company	1,500 tonnes/year	€250–450/tonne on the private market, as low as €35/tonne to private contractors	Initial investment cost for complete set-up with machines etc. at about €700,000–800,000	€25/tonne
Case study 2: Vapothermal Carbonization (Germany) Company	13,688 tonnes/year	€120–150/tonne for average quality biomass (lignite level quality)	Starts around €750,000 depending on plant size and degree of automation	€50/tonne
Case study 5: Gasification (Sweden) University	876 tonnes/year	€100	Gasification lab-scale: €150,000 Gasification commercial scale: N/A	€36/tonne
Case study 6b: Reed Bed System (Poland) University	100 tonnes/year	Not applicable	€130 material cost/m²	No running costs when installed, about €20/tonne for collection and supplying of beach wrack into RBS
Based on composted material				
Case study 3: Biocover (Denmark) Municipality/University	Not applicable	Not applicable	The municipality has existing machinery, therefore initial investment is only around €20,000 but approximately €70,000 for a new machine. €13,000 for facilities, if the municipality does not have a free area available	€25/tonne
Case study 4: Use for coastal defence structures (Russia) University	Not applicable	Not applicable	Lorry (1 day collection and transport of BW and 1 day transportation and infield planting), construction of composter container	50–100 man-hours per 50 m² greenery

Table IV Table showing the economic data used in the analysis.

It is essential to take the preconditions of the case studies into account when drawing conclusions based on the data:

- Case studies 1 and 2 were performed by companies. The data provided by these case studies is based on the scale of an actual processing facility.
- Case studies 5 and 6b were performed by research institutions and the provided data is based on knowledge gained from a small lab/pilot-size scale. The data for case study 6b was provided for an installation of 1 m². To make the calculations compatible, we scaled the data to an installation of 1,000 m² and lowered both the investment cost and running cost/m² accordingly.

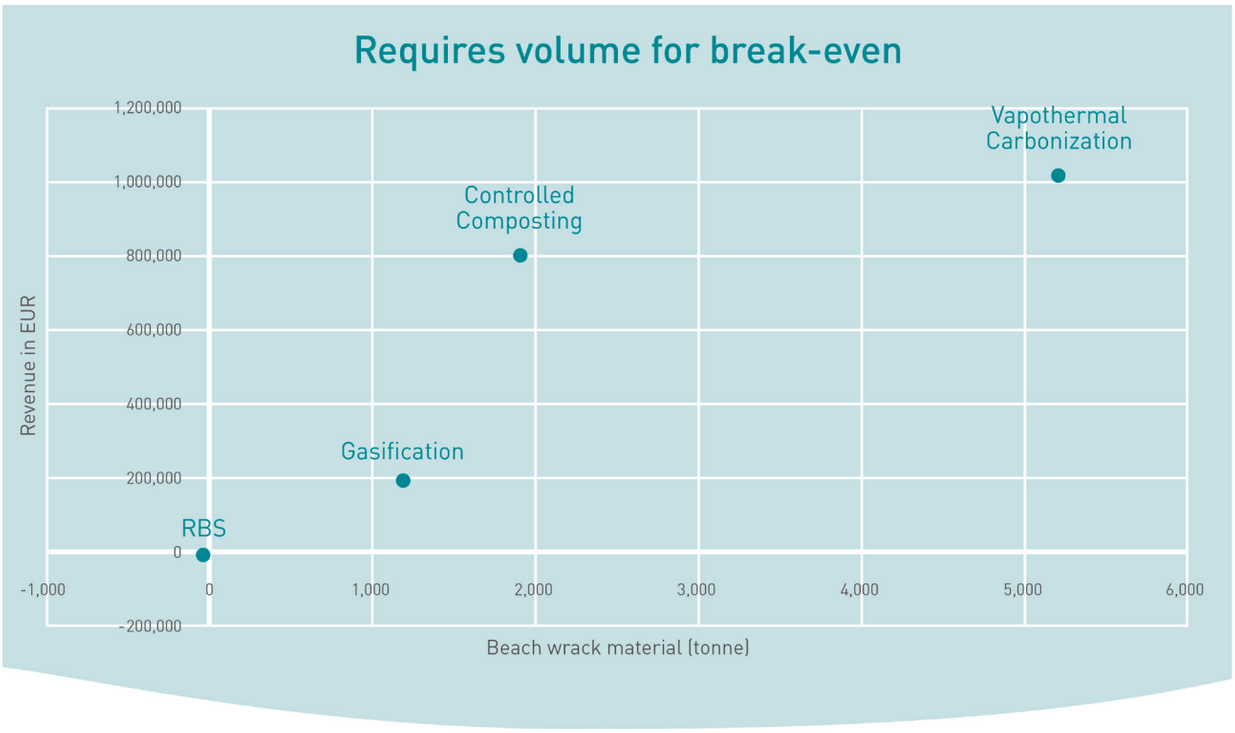


Figure I showing the required volume of beach wrack needed to reach break-even for the four treatment options.

- Case studies 3 and 4 researched methods where the economic value was subordinate to the environmental value, i.e. the focus was not to develop a feasible solution from an economic perspective. For this reason, they are not included in the further economic calculations, but will be discusses separately.

Break-even analysis

The → Figure I "Required volume for break-even" describes (a) how much beach wrack material and (b) how much in sales each treatment option requires to reach break-even. The revenue is based on a scenario where all the end-product is sold at the price point provided by the case studies. If the price point changes or if all product is not sold, it will affect the calculations significantly. A handling fee of €60 was added to the revenue for each treated tonne of material. The fee is a significant part of the revenue. The analysis does not take time into account. Based on the analysis, the Reed Bed System has no possibility of achieving a break-even point, while the other three treatment options may do so under the right circumstances. The treatment options are positioned as such in relation to each other:

- Vapothermal Carbonization needs to generate the most turnover in terms of both in processed volume and money to reach break-even.
- Controlled Composting is positioned in the centre of the table, requiring a relatively low amount of material to reach break-even.
- Gasification at the bottom left needs the least turnover within both variables to reach break-even.
- The Reed Bed System does not reach break-even, regardless of volume.

Between the options that may reach break-even, Vapothermal Carbonization requires the most material, Gasification requires the least material, and Controlled Composting requires slightly more than Gasification. If the supply of raw material does not reach the volumes required by a specific treatment option, it is unlikely to generate profit. In our analysis, 1,210 tonnes (Gasification) is the least amount needed to reach break-even. The Gasification case study was performed at lab scale. The least amount of material needed to reach break-even in a case study performed by a company is with Controlled Composting, which requires 1,948 tonnes. Between Controlled Composting and Vapothermal Carbonization, there is a need for an additional 3,224 tonnes. Furthermore, the treatment options **differ in their ability to cope with an uneven inflow of material**. Based on the process times (displayed in → table I) we know that Vapothermal Carbonization and Gasification have short processing times, while Controlled

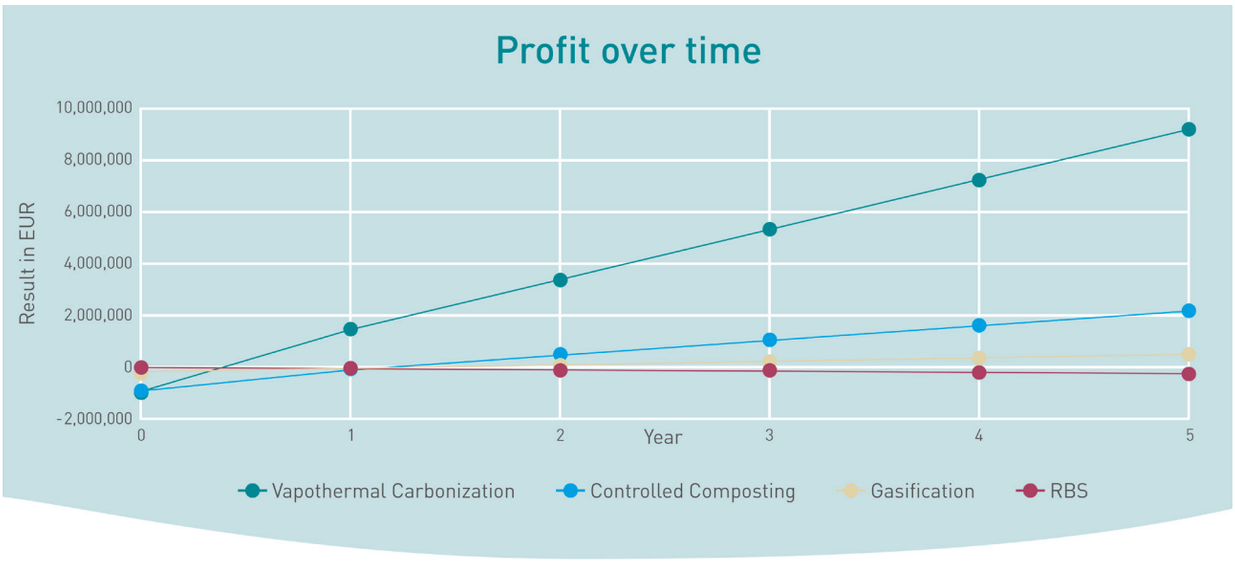


Figure II Table showing the expected profit over time for four treatment options.

Composting and the Reed Bed System have long processing times. This implies that Vapothermal Carbonization and Gasification require a steady and even supply of material to reach their full capacity, whereas Controlled Composting and the Reed Bed System can accept large quantities on a single occasion followed by a period without material deliveries.

Profit over time

Profit over time visualizes how the results of the respective case studies will develop over time. The analysis is built on a scenario where each solution runs at full capacity during a five-year period, has access to material as required, and sells all end product. The model has not taken factors such as deprecation costs and efficiency loss into account, and the model therefore visualizes a straight curve instead of a more realistic downward curve.

The → Figure II shows that Vapothermal Carbonization reaches a positive cash flow during the first year with a gross profit of EUR 1.2 million. Controlled Composting and Gasification reach break-even during the second year running. The Reed Bed System has a negative gross profit, thus shows a negative result of €200,000 after five years. After a five-year period, the treatment options with positive results show the following gross profit:

1. Vapothermal Carbonization: EUR 9.1 million
2. Controlled Composting: EUR 2.1 million
3. Gasification: EUR 0.4 million

- The analysis shows that supply of material is a key factor for economic feasibility. Based on experience from the CONTRA project, we know it to be challenging to secure material and even more challenging to secure a steady inflow of material. This is a key aspect of feasibility.
- For treatment options that require large amounts of material, it is likely that material needs to be sourced from several landing sites and/or supplemented with other organic materials.
- If the demand for beach wrack material goes up, it is likely that the handling fee will go down. This is an aspect that needs to be considered in further economic analysis. In fact, such trends were observed in northern Germany during the project period.
- The analysis shows that, under the right circumstances, there is expected profitability in treatment options based on beach wrack.

Innovation and implementation

The focus of most beach wrack management today is removing and disposing of the beach wrack material with as little effort and cost as possible, with the sole aim of offering enjoyable beach experiences. This style of management does not take potential values associated with environmental impact and circular and/or economic possibilities into account. Progressive key stakeholders are either in the early phases of redesigning their beach wrack practices or not content with the outcome of their efforts.

The aim of the CONTRA project was to research and, if possible, facilitate a shift to a scenario where beach wrack management is based on research, circular models, and innovative ways of utilizing the material in value-adding processes. Innovation can be described as the introduction of something new into a context where it is applied and creates value. According to this definition, an idea or a novelty is not innovative by itself, but rather becomes an innovation when it is applied and creates value. The definition highlights that the step from research (idea, pilots) to practical implementation (scale and contextualization) is as challenging as the idea leading up to innovation is brilliant (Olsson, 2015)

A novel approach to beach wrack management is to *collect and utilize* the material. The collect and utilize approach is a holistic approach which takes several layers of value and needs into account. Such values are the environmental benefits of collecting and utilizing beach wrack in controlled processes (e.g. GHG mitigation, nutrient removal from the Baltic Sea) and the economic value of a clean beach. Furthermore, the holistic approach includes the ambition to utilize the material in circular models. Going forward with the analysis, we adapt the holistic approach (→ Figure III) and the full complexity of beach wrack management, including the ambition to seek solutions where maximum value is created.

The following chapter is dedicated to the introduction of new ideas that may lead to innovation in the beach wrack sector. The ideas will be presented in the form of *value chains* and *business models*. The value chains and business models build on the research brought forward in the report and put it in a practical context, i.e. closer to implementation.

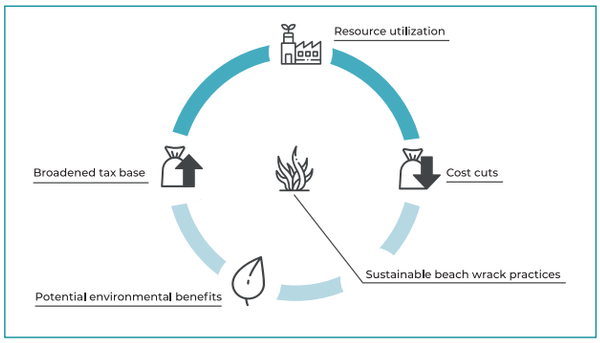


Figure III Holistic approach to beach wrack management, illustration: Sofia Nilsson (Krinova)

The aim is to let them serve as inspiration and guidance to beach wrack stakeholders in the BSR. Concluding the chapter is a proposed process that can be used by stakeholders willing to explore their respective site-specific possibilities to implement novel ideas in practice.

> **“Currently, in some municipalities, the conversation about sustainable beach wrack treatment has not even started. Other local authorities are trying hard to independently find affordable, legal and worthwhile operations, but are being restricted by having limited resources, a lack of knowledge and a lack of cooperation from the authorities and various stakeholders.”**
>
> (Hofmann et al., 2021).

Beach wrack value chains

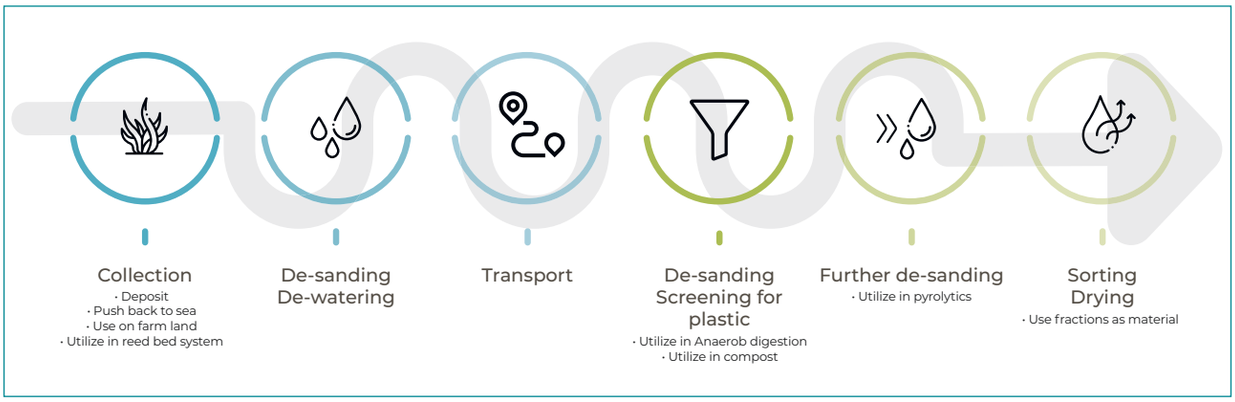
Zamora (2016) describes a value chain as a range of activities performed with the aim of bringing a product or service to market. A value chain takes all activities into account, ranging from conceptual work and sourcing through different phases of production, sales, distribution and eventually final disposal after use. The subject in a value chain analysis is not necessarily a company, as the same logic applies to municipalities and other organisations. In business development, it is common to plot value chains with the aim of finding more cost-effective ways of achieving desired value. The target in such a process can be to achieve similar or higher value with less cost and/or effort. This can be achieved by altering different stages of the chain, for example by adding new technology or methods. In the beach wrack-context, a value chain can be used to describe and understand how value and opportunities change as different activities are performed. It can also be used to analyse the efforts needed to utilize the material in different treatment options, hence comparing the feasibility of the treatment options (→ Figure IV).

First leg of the value chain: getting the material in shape

The first leg of the value chain is focused on layering pre-treatment steps which the treatment options need as regards material quality. Focus is on the treatment options researched in the CONTRA project, but some other practices are included as well.

- The first step in the value chain is to collect the material. This step adds value to the material by gathering it in a smaller physical place. Connected to the first step, you find the common practice of pushing the material back into the sea. In the third step, you also find case study 4 – *Use for coastal defence structures* – which is accessible by moving the material to the back of the beach.
- The second step in the value chain is initial de-sanding and de-watering. This step adds value to the material by reducing its weight and by removing sand.
- Figure IV First leg of the beach wrack value chain, illustration: Sofia Nilsson (Krinova)
- The third step in the value chain is transportation of the material. This step adds value to the material by relocating it to where it can be utilized. Connected to the third step, you find the common practice of deposit to landfill and direct use on farmland. In the third step, you also find case study 6b – *Red Bed System* – which can be installed near the place of collection.
- The fourth step in the value chain is de-sanding and screening for plastic and other litter. This step adds value by preparing the material to be utilized in *Controlled Composting (case study 1)*.
- The fifth step in the value chain is further de-sanding, which is needed to obtain good output from *Gasification* (case study 5) and *Vapothermal Carbonization* (case study 2), which are the treatment options available at this stage.
- The sixth step in the value chain is drying and sorting through which fractions, such as eelgrass, can be made accessible.

Figure IV First leg of the beach wrack value chain, illustration: Sofia Nilsson (Krinova)



As described in → Figure IV, treatment interventions gradually unlock new ways of utilizing beach wrack. All treatment options require basic collection, but from there the material needs to be upgraded in the value chain to be suitable for use. Case study 3 (Biocover) is not represented in the value chain, as this treatment option builds on a composted material, such as the end product from "Controlled Composting".

> The legality of direct use of organic material on farmland or deposit to landfill is not clear in BSR countries. Today it is practiced with exemptions given by authorities.

Second leg of the value chain: getting the product to market

Each treatment option researched in the CONTRA project has its own continued value chain. On display in this section is the process of **Hanseatische Umwelt CAM GmbH** (HU), a waste management company operating from Sandhagen outside of Rostock in northern Germany. During the project period, HU researched and developed several special soil improvement mixtures utilizing beach wrack (treibsel) in the compost. In parallel, the company worked on business development in cooperation with a team of business designers from Krinova. The process resulted in a business model in which the value of the product was communicated in an innovative way. Focus was turned towards the advantages of using marine biomass and the nutrient cycle which is established by producing soil improvement products from marine biomass. Further, the target customer base was widened, and attention was put to small scale gardens and indoor plants where soil quality is of great importance. Controlled Composting is one of the treatment options with expected profitability over time. The full business model will be covered in a later chapter of this report. The step-by-step value chain from the arrival of the material to use by the customer is presented below.

1 Use of beach wrack as co-composting material.
2 Setting up the compost pile with 70 % green waste and 30 % beach wrack.
3 Composting with regular turning of the piles (approx. every 4 weeks) by an excavator.
4 Continuous monitoring of temperature.
5 After about 3–5 months: screening the compost to get the final fine compost material (usually 20 mm mesh size).
6 Collection of samples for laboratory analyses of the compost batch.
7 Screened compost material is used to prepare the soil mixture by adding mineral additives, sand and fertilizer.
8 Mixing of the different soil substrate types containing beach wrack-based compost (lawn soil, garden soil, black soil).
9 The final soil substrate is screened with a 12 mm mesh size to get real fine soil substrates with less impurities.
10 Storage of ready-to-sell soil substrates.
11 Filling of soil in the final packaging.
12 Selling of the soil to private and professional customers.
13 Use as soil improvement product.



Photo III Product development at Hanseatische Umwelt CAM GmbH (case study 1), photo: J. Almqvist.

Innovating the value chain

By introducing novel ideas and/or new technology into the beach wrack value chain, value can be created with less effort. One way of adding value is by making one or more of the steps of the value chain more effective. In this section, we will introduce two possible ways of innovating the first leg of the value chain by introducing novel ideas.

Organic biomass-collection from water

In this example, innovative technology is introduced in conjunction with a new approach to beach wrack collection, namely offshore collection. Offshore



Photo IV Offshore collection of beach wrack (development phase), photo: BrainBotics IVS.

collection of beach wrack is one possible way of altering the value chain, making it more efficient and adding value to the collected material. This is possible by utilizing unmanned offshore collection robots developed in collaboration between the companies BrainBotics and RanMarine (photo IV). Using this technique, the material is collected from shallow waters before it lands on the beach (Søren Pallisgaard personal comment via e-mail conversation). By introducing this new approach and technology:

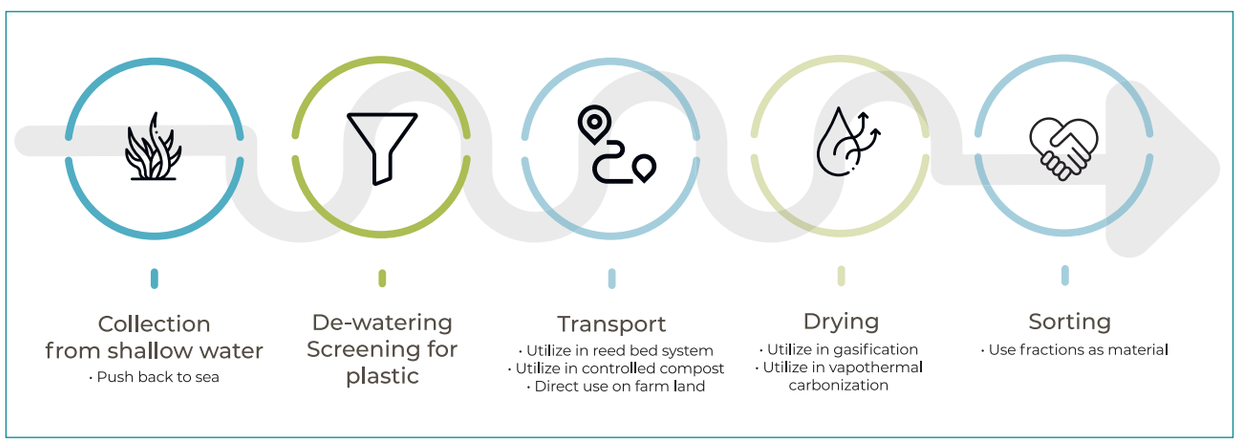
- The material can be collected with a very *low sand content.* This leads to a shortened value chain as it eliminates the process of de-sanding the material.
- The material is collected in a state *before degradation*, which has positive effects on treatment processes where fresh material is needed.
- The material is collected with less *variation* regarding decomposition, which leads to more stable and predictive treatment processes.

So far, the solution by BrainBotics and RanMarine is in a research phase, where small robots were used to gain experience in how to scale up to a commercial solution (https://rimanetwork.eu/wp-content/uploads/2020/11/RIMA_A4_PROJECT_RAHIP-scaled.jpg). The companies are currently developing a larger robot platform under the name SACAR, which will be able to collect larger amounts of material. Offshore collection of blue biomass is not generally in line with interpretations of environmental protection policies. The main reason is that further research is needed regarding the role the material plays in the ecosystems of shallow waters. Still, offshore collection is a possible way of altering the value chain towards higher value, dealing proactively with the challenge.

Education and mindset

Mossbauer et al. (2012) conducted test runs with staff operating beach cleaning machinery. By training and educating the staff, the sand fraction in the biomass was reduced by 50 %. According to these authors, the "offering this training in more coastal communities would reduce sand loss and improve the effectiveness of beach wrack treatment". Hence, the introduction of novel ideas through education can create value in a beach wrack management context. As mentioned, methods (how to collect the material without including the sand as well) are of great importance, but the notion of a collect and utilize mindset, i.e. that the material will be utilized further along the value chain, is of equal importance.

Figure V Alternative beach wrack value chain where the material is collected in the water, illustration: Sofia Nilsson (Krinova)



Business models

In this section business models will be used as a tool for understanding and discussing aspects of sustainable beach wrack management. According to Osterwalder & Pigneur (2010) business models, in its essence, can be described as "the rationale of how an organisation, creates, delivers and capture value". Osterwalder & Pigneur (2010) designed a tool that made business thinking accessible called the Business Model Canvas (BMC), which is a widely used tool in business development. The BMC illustrates the business model at a given point in time in a **qualitative manner**. Business models in canvas format are an intuitive tool for business development and a handy graphical format when it comes to displaying interactions and interdependencies in a business environment.

However, the beach wrack ecosystem is more complex than most business environments. It includes private companies but also public organisations, it creates value on a business level but also on an environmental and societal level. Building on the Business Model Canvas, PPPLab Food and Water developed the Public Private Partnership Canvas (PPPCanvas). Whereas the original BMC is designed solely for mapping company business models, the PPPCanvas has a development focus and pays attention to secondary effects such as environmental benefits. For further reading about the PPPCavas please refer to (https://ppplab.org/2017/11/pppcanvas/)

In this section the PPPCanvas is applied as a tool to display possible beach wrack management scenarios/cases. They will be referred to as business models or simply models. The models were designed by Krinova in cooperation with case study representatives. In the process the further application and feasibility of the different treatment option have been discussed and specific attention was put to aligning the case study treatment options with potential business opportunities.

Business Model 1: A beach management company

Challenge: Throughout the BSR there is a lack of clear policy of recommendations and management strategy regarding beach wrack. Research by Mossbauer et al. (2012) describes that beach cleaning in northern Germany is performed with low standardization i.e. there is a lack of established good practice. Based on research in the CONTRA project, this observation can be transferred to other countries in the BSR as well. This leads to a wide range of actual practices, often performed by personnel with limited insights into beach ecology and good practice regarding collection techniques. The material is generally treated as snow in the winter or falling leaves in the autumn, i.e., as a nuisance which should be removed as quick and effortless as possible. Further the potential use for the material is rarely accounted for in the management practices which inevitably leads to low quality material in the instances where there is an available treatment option in the region.



Photo V Business Model workshop in Sandhagen, Germany, photo: J. Almqvist.

The proposed business model (→ Figure VI) addresses the challenge by introducing a research-based and environmentally considerate beach management service. The company's value proposition is built on the latest research e.g., from the CONTRA project and utilize specialized equipment which is handled by trained professionals. By doing so, the company may unlock several aspects of value and become an attractive option on the market.

When beach management operations are disengaged from local internal logic (municipalities handle their own management) to a regional and scaled operation several advantages emerge:

- Market size: The operation can serve to the needs of several beach wrack stakeholders.
- Builds infrastructure: The operation enables cooperation with treatment facilities as the company becomes a supplier of material. By meeting the treatment facilities requirements



Photo VI Pilot installation of a Red Bed System, photo: A. Kupczyk.

for material quality, a cooperation can prosper.
- Specialization: A scaled operation can support specially trained personnel and investment in machinery and innovative technology such as the of shore collection system SACAR.
- Unlocks value: Trained personnel can distinguish beach wrack from its more valuable elements. Two known components with high value (and market demand) are eelgrass (*Zostera marina*) and red seaweed (*Furcellaria lumbricalis*).
- Sustainability: Strengthened beach wrack infrastructure and know how enables environmental benefits.

Contra case studies in play

Research (such as the output from CONTRA) in the scope of ecology and sustainability is the corner stone of the business model. Further, trained personnel enable business opportunities within the business model, one such opportunity is the ability to install on site treatment options in the coastal zone. Such installations are the Reed Bed System (case study 6b) and Coastal Defence Structures (case study 4). The RBS (Reed Bed System) – as described in the section about innovative treatment options – is specially designed to be positioned close to the landing site thus reducing the need for lengthy transports. A beach wrack management practice where shallow water collection alongside the RBS is introduced would be an option for sites where the amounts of beach wrack is limited.

Figure VI Business model describing the logic of a beach management company, PPPCanvas is designed by PPPLab

The PPPCanvas

Beach Wrack Business Ecosystem

Beach management company

Key Partners
1. Manufacturer of specialized machinery.
2. Beach health researchers.
3. Companies utilizing Beach wrack in various treatment applications.

Key Activities
1. Contract procurement.
2. Relationship building and lobbyism.
3. Beach management.
4. Sales of beach wrack material.

Value Proposition
1. Attractive beach experience.
2. Research-based and environmentally-conciderate beach management service.
3. On-site/beach installations using blue biomass materaial as building material.
4. Collection of beach wrack material which meets treatment process needs.

Customer Relationships
1. Long-term contracts, steady cooperation.
2. Common sustainability goals.

Customers
1. B2P - Public beach health stakeholders such as municipalities.
2. B2B - Private beach health stakeholders such as camping sites, and hotells.
3. B2B - Companies sourcing pure material such as elgrass.

Extended Beneficiaries
1. Beach tourists.
2. Local residents.
3. Entreprenours:
   - Tourism sector
   - Restaurants
   - Vendors
   - etc.

Governance
1. Common goal and joint effort with beach health stake holders and processing facilties.

Key Resources
1. Staff with experience in professional beach cleaning.
2. Contracts on beach management.
3. Specialized maschinery.
4. Drying and de-watering fascility.

Channels
1. B2B and B2P.
2. Direct contact.
3. Few relationships/ partnerships.

Cost Structures
1. Staff and facility costs.
2. Machinery hire/purchase.
3. Staff training.
4. Fees related to upcycling/disposal of material.

Impact
1. Decrease nutrients and heavy metals in the Baltic Sea
2. Erosion defence
3. Enhanced ecosystem services in cities.
4. Attractive beach
5. Increased Tax income through increased visiting frequencie.

Revenue Streams
1. Management fees.
2. Sales of beach wrack material.
3. Innovation support/public compensation.

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Strengths	Weaknesses
— Benefits of scaled operation — Trained specialized personnel. — First to market.	— Model is dependent on treatment facilities as customers.
Opportunities	**Threats**
— Company may control flow of beach wrack material. — Legal changes may regulate collection and utilization leading to increased demand	— Lack of material/no available procurements in the region. — Legal changes regarding beach wrack collection. — Decreasing amounts of beach wrack.

Table V A SWOT analysis of Business model 1.

Business model 2: Treatment facility – product to market

Challenge: The successful utilization and processing of beach wrack as a resource calls for innovative thinking in all steps of the value chain. Though there is a potential to be profitable there are few available treatment facilities in the BSR. While much effort has been put into refining techniques for collection, pre-treatment and processing little attention has been put to the end product and its position on the market. Today most compost based on beach wrack is sold in volume at a low price point. Viable business models based on beach wrack requires an attractive end-product as well as established sales channels that reach customers with a willingness to pay.

The proposed business model (Photo VII) addresses the challenge by introducing *added value* such as: storytelling, and customer packaging into the value proposition. Added value: refers to the products properties such as "recycled nutrients". *Storytelling*: refers to the way the product is positioned on the market e.g., "biomass from the Baltic Sea" and/or "produced by Mr. Staemmler". *Customer packaging*: refers to limiting the packaging volume to the needs of a private consumer.

When attention is put to the steps of the value chain closer to the consumer several advantages emerge:

— Profitability: Consumer packaging enables higher price/quantity.
— Larger and more diverse market: Consumer packaging opens sales channels such as nursery-gardens and DIY (Do it yourself)-markets.
— Product properties: Added value mediates the products technical properties: in this case: The product contains algae and seagrass from the Baltic Sea which has positive effects on root growth and water holding capacity.
— Desirability: Story telling mediates the products emotional properties, in this case: environmentally friendly, saves the Baltic Sea, works wonders on in your garden.

Photo VII Prototype of consumer packaging for compost based on beach wrack, illustration: Hanseatische Umwelt CAM GmbH.



Photo VIII Pilot Installation of a Biocover in Köge municipality, photo: J. Engelbreth Larsen.



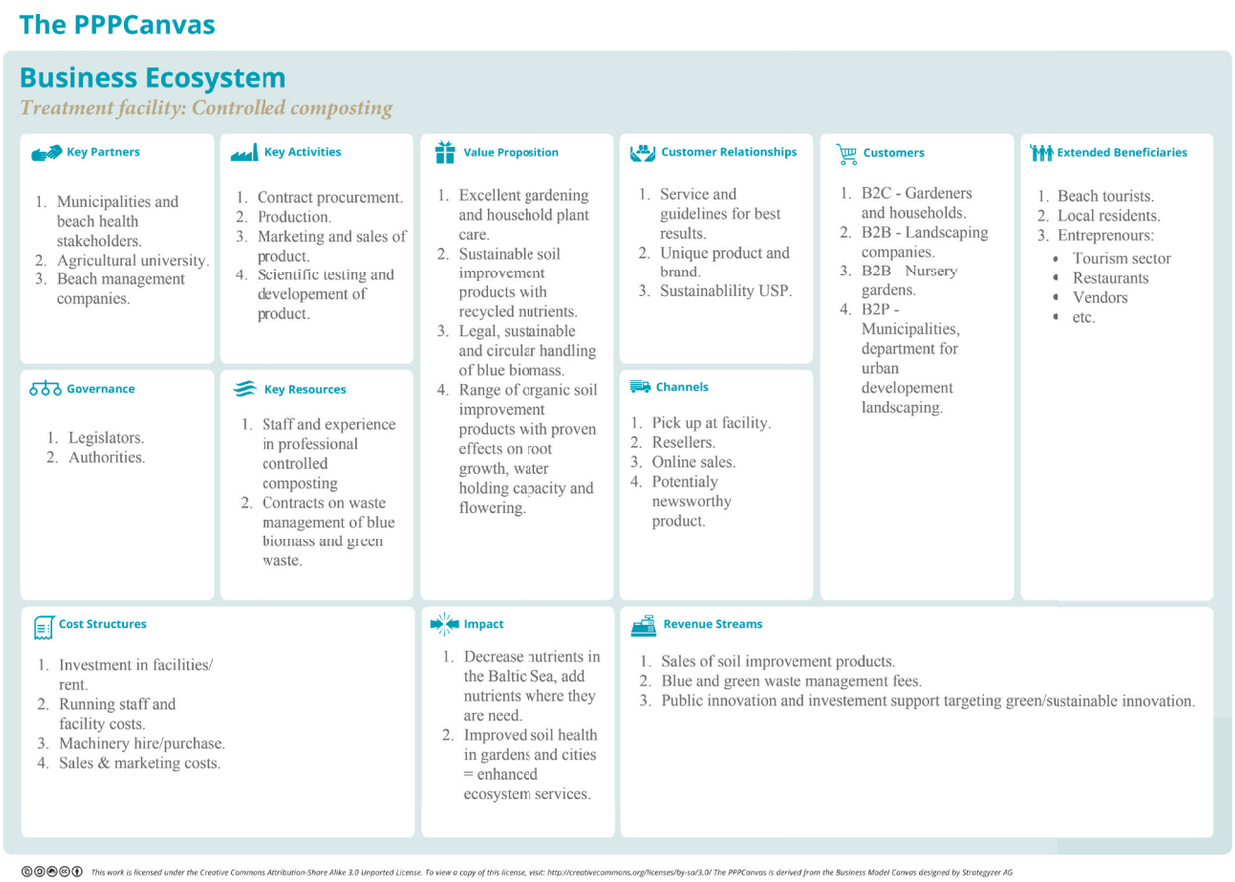
Strengths	Weaknesses
— Profitable operation (as shown in → table VI) — Strong added values — Low tech solution that can be incorporated in existing facilities e.g., where green biomass is treated today. — Legal treatment option — Can receive material in large batches.	— Treatment volume is limited. — The operation requires a large facility as both input material and end product is voluminous.
Opportunities	**Threats**
— Treatment method and know-how can be packaged and sold as a service.	— The company is dependent on relations with partners (municipalities, beach management companies) to obtain material. — Decreasing amounts of beach wrack.

Table VI A SWOT analysis of Business model 2.

Contra Case Studies in play

Business model 1 is based on case study 1, Controlled composting. However, the general logic of the model can be applied to case study 2, Vapothermal Carbonization, as well. Further, composted beach wrack material is the main building block of the Biocover (case study 3). The Bio cover reduce GHG emissions by placing the compost on top of the landfill. The methane-oxidizing bacteria in the compost convert methane to CO_2 which is 25 times less potent than methane.

Figure VII Business model describing the logic of a controlled composting facility, PPPCanvas is designed by PPPLab



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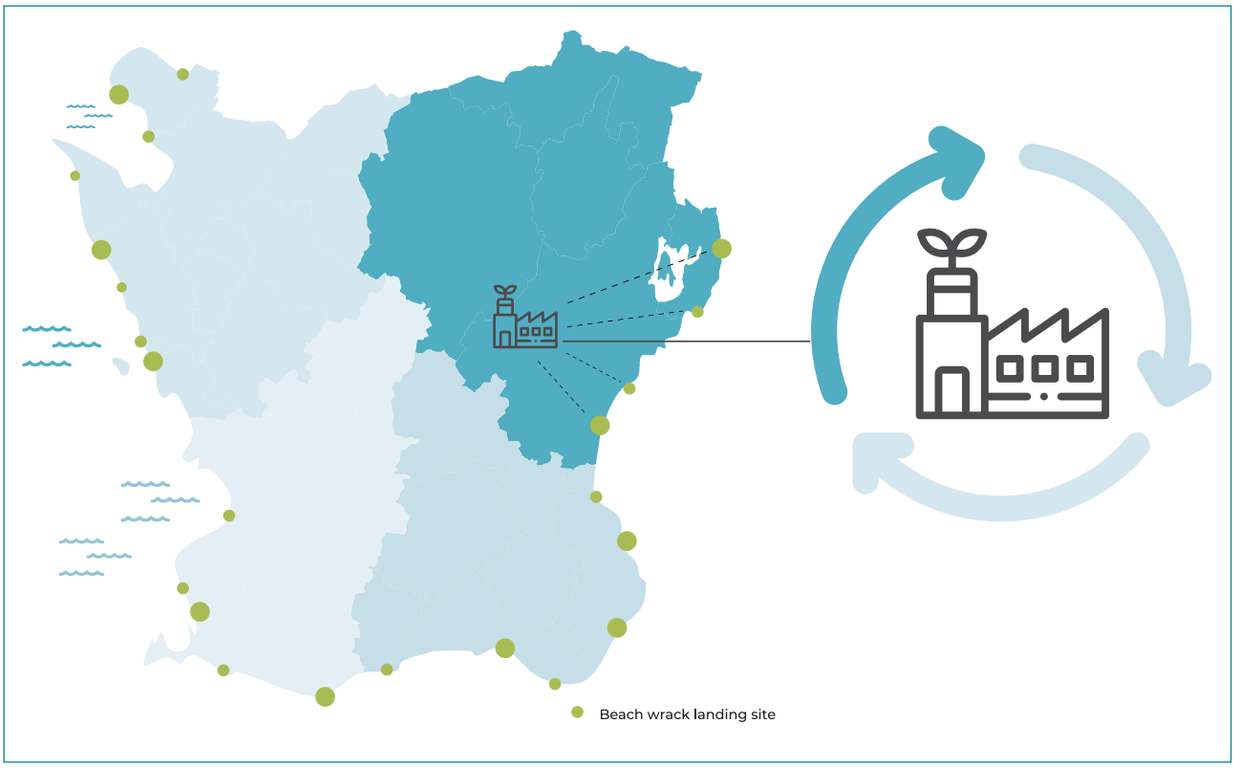


Figure VIII Graphical representation of regional cooperation with shared infrastructure, illustration: Sofia Nilsson (Krinova)

Business model 3: Regional cooperation

Challenge: Regions where large amounts of beach wrack is washed ashore have multiple stakeholders sharing the need to collect and remove material. Such stakeholders are e.g., municipalities and private beach-health stakeholders (hotels, camping owners). Today management of beach wrack is seldom carried out in regional cooperation, rather the common procedure is quite the opposite. Mossbauer et al. (2012) described the common management practices to be extraordinarily site specific and points out that "communities own and maintain their own cleaning machinery". Further Mossbauer et al. (2012) mentioned that "gear or personnel exchange between authorities of different coastal sections is not common practice" and that "efficient operation of recycling facilities (requires) a regular supply of raw material of a nearby beach".

The proposed business model (→ Figure IIX) addresses the challenge by introducing cooperation and joint investments in infrastructure such as treatment facilities.

The approach is based on a common (regional) will to collect and utilize the material and draws inspiration from regional cooperation on other common grounds/challenges. From a practical perspective inter-municipal cooperation could range from joint procurement of machinery and/or beach management consultants to joint investments in infrastructure and treatment facilities. In this model focus is on establishing a joint treatment facility.

> "It is difficult for a municipality to bear the cost of collection, storage, transportation and composting of beach wrack. Therefor municipalities chose the easier option of collecting beach wrack short-term, before pushing it into the sea. Additionally, the municipality may lack facilities and machinery for the task of carefully collecting beach wrack, so it is free of sand.
>
> Sara Hillbom Guizani (Køge Municipality)

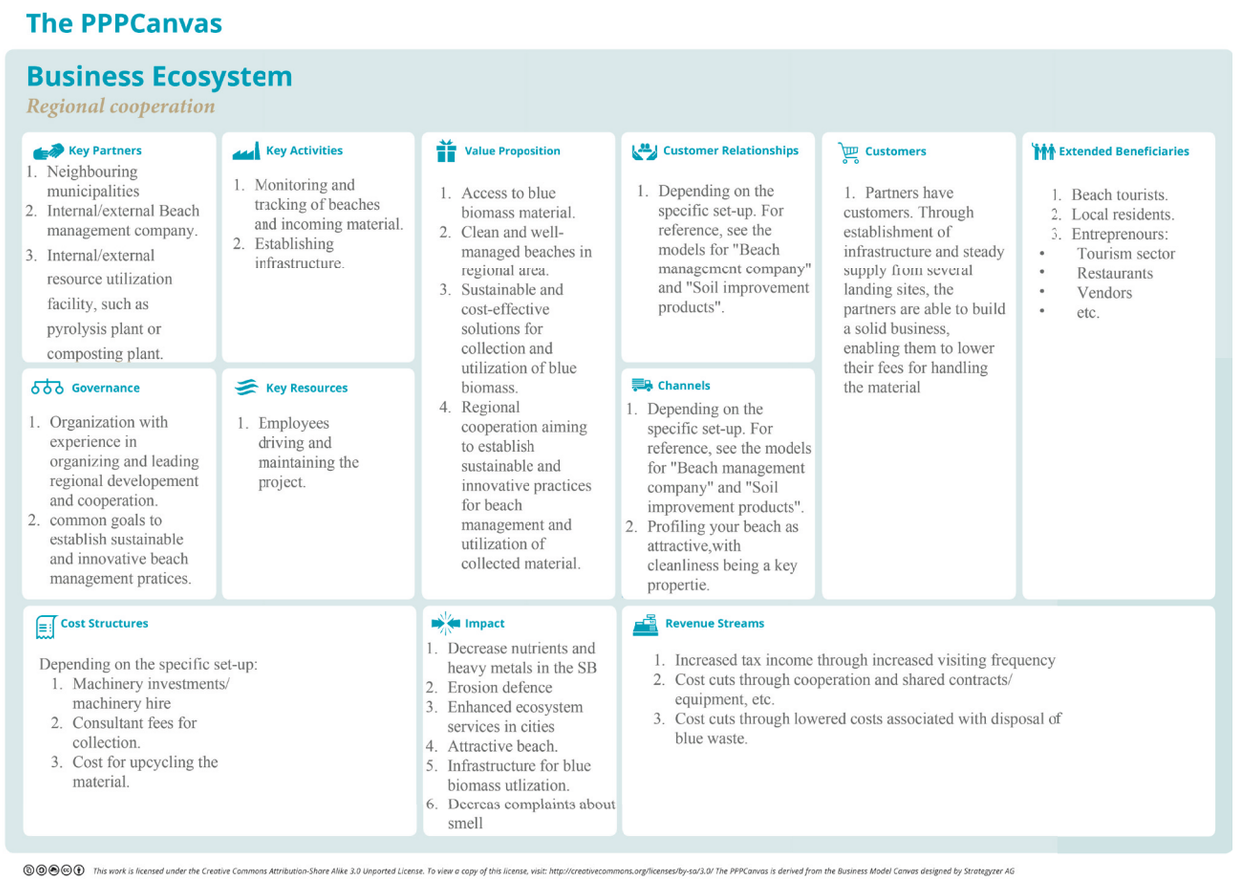
When beach management operations are carried out in regional cooperation several advantages emerge:

- Infrastructure: Shared investments in infrastructure make large-scale legal and sustainable utilization of beach wrack material accessible and affordable to several stakeholders in one region.
- Enables innovation: A scaled operation can support investment in machinery and innovative technology such as the of shore collection system SACAR or a large-scale treatment facility such as Controlled composting (case study 1), Vapothermal carbonization (case study 2), or Gasification (case study 5).
- Incentives to recycle: Beach wrack stakeholders with investment in treatment facilities give incentives to monitor landings and utilize material when it is in good shape.
- Environmental benefits: Strengthened beach wrack infrastructure enables environmental benefits (see chapter "Environmental comparison").
- Access existing infrastructure: Treatment options can be integrated in existing infrastructure, e.g., controlled composting could be carried out in the same facilities where green biomass is handled.

Contra case studies in play

Depending on the site-specific needs and how the cooperation is set up, all CONTRA case studies could be interconnected with the business model. If the amount of material in a region is extensive there is reason to consider the more investment heavy options such as Vapothermal Carbonization (Case study 2) or Controlled Composting (Case study 1). These solutions have high investment costs but offer utilization of large amounts of material. If compost is produced in the cooperation possibilities to either sell the material as soil-improvement products or utilize it in applications with environmental impact values such as the Biocover researched in case study 3.

Figure IX Business model describing the logic of regional cooperation, PPPCanvas is designed by PPPLab



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Strengths	Weaknesses
— Commitment to sustainable practices. — Shared cost for investments. — Enables sustainable and legal practices. — Lower costs to keep beaches attractive.	— Public companies are not allowed to make profit. — Political agreement across organizational borders is needed. — Transportation of material from landing to utilization.
Opportunities	**Threats**
— Investment support through sustainability funds. — Position region as innovative.	— Decreasing amounts of beach wrack.

Table VII A SWOT analysis of Business model 3.

Suggested development process

Implementing novel ideas requires a process which guides stakeholders and innovation leaders from an undesired situation towards a desired situation. In the case of beach wrack management, it involves shifting from a strategy based on remove and dispose towards a strategy based on a collect and utilize mindset. It is our hope that the published model coupled with the reports published by the CONRA partnership will serve as guidance and inspiration in establishing sustainable beach wrack practices going forward.

- Step one: research the local context. This step puts attention on easily accessible data about the context you are working in. It will lead to general insights about e.g. where there are beach wrack landings.
- Step two: define the challenge, i.e. the problem in the geographical area (specific beach, municipality, region). This step focuses on whether the geographical area has a beach wrack challenge or not. If it does, the nature of the challenge is described.
- Step three: inventory the knowledge within your organization. This might lead to insights about previous projects, relationships with co-workers with previous experience and a definition of knowledge gaps in the organization, e.g. legal aspects.
- Step four: identify stakeholders in the region and open up a dialogue with them.
- Step five: define common goals with the identified stakeholders. This step is important because this is when values that feed into the strategy are defined. For example, stakeholders could agree that beach wrack should be treated as a resource if possible.
- Step six: compile all of the previous steps into a strategy which could be used to establish political consensus.
- Step seven: focus on how everything comes together. In this step, the PPPCanvas could be used as a tool. Stakeholder contributions and responsibilities are defined in the process.
- Step eight: implement the strategy.

Figure X Suggested process for implementation of novel ideas, illustration: Sofia Nilsson (Krinova)

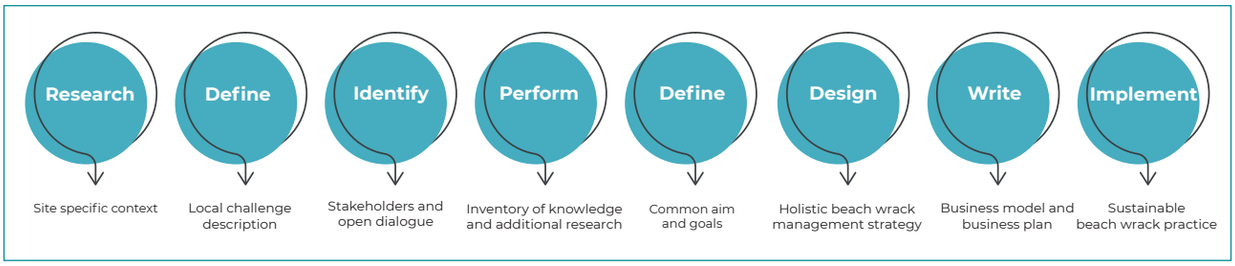




photo: © Nazarri/EUCOD

Conclusions

We conclude that beach wrack is a challenge across the Baltic Sea Region (BSR). When the material occupies coastal zones, they are perceived as less attractive, thereby resulting in a decrease in visiting frequencies. Beach wrack stakeholders are keen to keep their beaches attractive, as they are a key element of a successful tourism sector. Stakeholders therefore invest resources to keep beaches clean by removing the material. The common practice today is to *remove and dispose*, i.e. the efforts are often carried out without specific knowledge of the material, its ecological functions or its potential value. This report has shown that there is good reason to challenge this practice and encourage the introduction of alternative and more sustainable practices that apply a circular and resource-oriented mindset, what we call *collect and utilize*.

Economy, legal changes and environmental consideration are three core drivers that may accelerate the shift towards collect and utilize practices.

- This report has shown that business models based on beach wrack have the potential to be profitable.
- This report has shown that legal policy varies across the BSR, and has also put forward reasoning which points toward a more resource-oriented legal framework.
- This report has shown that there are several environmental benefits that can be unlocked through a combination of sustainable collection and utilization of beach wrack material.

The innovative treatment options researched in the CONTRA case studies offer both environmental impact and economic possibilities. In the comparison of the treatment methods, all showed potential to deliver positive environmental impact and three out of six showed potential to be profitable over time. This report has indicated that the total value created by collecting and utilizing the material far outweighs the investments made in beach cleaning efforts today.

The report has shown that access to beach wrack material is a key factor in economically viable business ventures. The industry built on beach wrack is almost non-existent in relation to the amounts of

potentially available material. One of the main challenges for developing the industry is building infrastructure that enables more material to be utilized. The authors have argued that more material will likely be made available for sustainable treatment if economic, legal and environmental perspectives are taken into account by all stakeholders.

The report has demonstrated how business thinking can be applied to the beach wrack challenge. During the project, the Krinova team worked closely with the CONTRA partnership in an ever-ongoing exchange of ideas and scientific results. Development tools such as value chains and business models were introduced and used as a means to facilitate novel thinking/innovation. Some of the results from this process are manifested in the three published business models:

- **The beach management company**, which operates in the first leg of the value chain
- **The treatment facility**, which operates in the second leg of the value chain
- **The regional cooperation**, which elaborates on infrastructure and joint investments between beach wrack stakeholders.

Amongst other things the business models demonstrated how the narrative of environmental value can be used in storytelling for beach wrack based consumer products and how all the innovative treatment options researched in the project can be integrated in various business logics.

The report has introduced a basic step-by-step process which could be applied by beach wrack stakeholders with the intention of shifting towards sustainable beach wrack practices. When designing holistic beach wrack strategies, it is important to account for the site-specific prerequisites, the aim of the strategy and an estimate of the total value created by any planned interventions. We suggest that – going forward – beach wrack stakeholders should consider the range of values and variation of treatment options introduced in this report and aim to build both physical and intellectual infrastructure which facilitates sustainable beach wrack practices across the BSR. Furthermore, the CONTRA project has jointly written a policy brief on beach wrack which includes both recommendations and an outlook (CONTRA-Policy brief).

Acknowledgements

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Rostocker Meeresbiologische Beiträge

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Sonderband



CONTRA: **Heft 31**

Beach wrack of the Baltic Sea – Conversion of a nuisance to a resource and asset (EU-INTERREG project)