Compendium

An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources

Autumn 2012

SUBMARINER Compendium

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Disclaimer

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An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources

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Executive Summary

Innovative approaches to the sustainable use of marine resources have recently received more and more attention as part of new European Commission initiatives.

As one of the operational proposals under the Innovation Union and Resource Efficient Europe flagships of the EU 2020 strategy, the strategy for a sustainable bioeconomy in Europe was adopted by the European Commission in February 2012. It aims towards the development of a more innovative and low-emissions economy, which uses biological resources from the land and sea as inputs to food and feed, industrial and energy production as well as bio-based industrial and environmental protection processes. The strategy is coupled with the Commission's Integrated Maritime Policy. More specifically with the "Blue Growth" initiative, which aims to harness the untapped potential of Europe's oceans, seas and coasts for job and growth whilst safeguarding the services healthy and resilient marine and coastal ecosystems provide. It is therefore linked with the EU Marine Strategy Framework Directive to reach good environmental status by 2021.

Meanwhile, the Baltic Sea Region (BSR) is characterised by a long-standing tradition of transnational cooperation especially in relation to maritime affairs. These have reached yet another level with the adoption of the European Union Strategy for the Baltic Sea Region in 2009. This first ever macro-regional strategy tries to provide an integrated strategic framework for the large variety of actors, policies and funding mechanisms within the region and link them to European policies.

The SUBMARINER Compendium has been designed to provide, for the first time, a comprehensive picture of the contribution the Baltic Sea Region could possibly make within these European wide initiatives. The current state of knowledge has been gathered and set against the backdrop of environmental, institutional and regulatory conditions for the following topics:

- Macroalgae Harvesting & Cultivation
- Mussel Cultivation
- Reed Harvesting
- Large-Scale Microalgae Cultivation
- Blue Biotechnology
- Wave Energy
- Sustainable Fish Aquaculture
- Combinations with Offshore Wind Parks

This provided a framework to carry out SWOT analyses for each of the given applications and lead to recommendations on how to best address the obstacles and limitations inhibiting widespread adoption. While each application exhibits different kinds of needs, a number of cross-cutting issues have been identified, and are expanded on in the "Overall Conclusions" chapter.

The Compendium has been brought together by experts from a wide range of disciplines and institutions across all BSR countries, which have joined forces within the three year long SUBMARINER project (2010–2013), part-financed by the European Regional Development Fund.

The Compendium shall serve as the background for the SUBMARINER Roadmap to be published in summer 2013, indicating the concrete steps to be taken in the coming years within the Baltic Sea Region so as to promote beneficial uses and mitigate against negative impacts. The Roadmap will be developed in a participatory approach and based on input from stakeholders across the Baltic Sea Region and beyond.

Macroalgae Harvesting & Cultivation

As a result of eutrophication, the amount of filamentous macroalgae throughout the Baltic Sea has increased. Precise figures are missing due to lack of monitoring, but especially in South Sweden and Denmark substantial amounts of beach cast assemblages in the range of 70,000–85,000 tonnes of dry weight per year can be found. Whereas it is difficult to use them as fertilisers on agricultural land due to the risk of high level metal content, there are promising results of pilot studies carried out in using these macroalgae as a locally available resource for biogas plants (compare: the methane yield of red macroalgae is approx. 60 % of terrestrial crops', e.g. maize's methane yields). The removal of beach cast macroalgae does not only lead to cleaner beaches, with positive impacts for the local communities, it also contributes substantially to nutrient reduction in the Baltic Sea, as macroalgae show a nitrogen content of 2–6 % of dry weight. Municipalities like Trelleborg (SE) or Solrød (DK) have already started to go into this direction. However, private investments are currently still hampered as there is no understanding of Natura 2000 provisions related to how much macroalgae removal is allowed, nor is there a mechanism to compensate for the ecosystem services provided. Consequently, the production chain still requires further development in order to show clear positive energy net value.

It is also possible to cultivate macroalgae in nearshore installations, but this still remains a relatively unexplored field in the Baltic Sea Region.

Mussel Cultivation

Despite being its most common macroorganism, the small size of Baltic Sea blue mussel – caused by slow growth due to low salinity – means that they can hardly be used in the world-wide thriving business of seafood. Mussel farming in the Baltic Sea can, however, serve as a possible measure to counteract eutrophication. Evidence from the available pilot sites show that on average 100–150 tonnes per hectare mussel biomass can be harvested every second year containing 1.2–1.8 tonnes of nitrogen and 0.08–0.12 tonnes of phosphorous. The biomass itself can be used as organic fertilisers for gardens and greenhouses or be processed into chicken or fish feed with the added advantage of reducing pressure onto fish stocks. Ongoing trials and studies show promising results for all these products. Existing technologies are working sufficiently well with solutions already in place to avoid damage from ice drifts.

It is, however, difficult to give an estimate of the potential total area available for mussel farming throughout the Baltic Sea as sites have to fulfil a number of criteria in order to show a positive net effect on the environment. For instance, a small to moderate bottom water exchange is important, in order to avoid oxygen depletion and resulting decreases in abundance and biodiversity of benthic communities immediately beneath the cultivation site.

Overall mussel farming may in some parts of the Baltic Sea become a commercially promising area for small and medium sized private enterprises on the condition that environmental services rendered by them, such as nutrient removal, are also paid for. The Åland government (FI) is about to accept mussel farms as an environmental compensation for expansion of open net cage fish farms and in Sweden an appropriate regulatory framework is expected to come to force in 2014, but a Baltic Sea wide overall approach is missing so far.

In addition, zebra mussels have a relatively high abundance and distribution range throughout the shallow coastal lagoons and estuaries of the Baltic Sea. It can be assumed that they show similar qualities to the blue mussel, but so far no farming trials have been carried out and thus only very few data are available.

Reed Harvesting

Even though an inventory of reed areas and their biomass is missing, it can be assumed that the total area of reed in the Baltic Sea's shallow bays and coastal lagoons has increased substantially over the last decades covering by now at least 300,000 ha with potentially a total annual biomass of approx. 1 million tonnes available for use. Reed has always been used as a source for various applications, but its qualities as a possible local renewable energy resource or an environmental remediation measure have so far not reached beyond the research community, and even experimental results are rare.

With an average calorific value of reed with moisture content of 20 % being 3.9 MWh/t and assuming that 15–20 % of the total aboveground biomass in the Baltic Sea could be used, its energy potential is no more than 4 TWh (compare: annual energy need of about 100,000 households).

But reed beds can also be considered as an effective method to remove excess nutrients from shallow coastal seas due to their high absorption potential for macronutrients, especially nitrogen. About 5,000–10,000 tonnes of nitrogen and 500–1,000 tonnes of phosphorus could be eliminated from the coastal sea annually assuming that 100,000 ha (30 %) of the total reed bed area could be harvested (compare: 1 % of nitrogen and 3 % of annual phosphorous reductions of target levels set by the HELCOM Baltic Sea Action Plan).

The economic feasibility of innovative applications for reed shows large regional variations. In order to make it profitable costs need to be cut over the whole process chain and ecosystem service has to be included in the economic valuation. Especially harvesting technology has to be further developed not only in light of better economics, but also in view of environmental concerns (i.e. no damage of the ground).

Applications are also highly affected by differences of the chemical composition and physical properties of the reed depending on the season. Biogas production and nutrient removal can for instance only be done with summer reed. It is therefore highly important to find solutions which determine how much reed can be harvested at which time without negative effects on the natural ecosystem services which reed beds provide as an important habitat for nesting birds, fish and benthos.

Large-Scale Microalgae Cultivation

The global need for bioenergy is increasing and microalgae may be part of the solution. The biorefinery concept offers hope in its ability to integrate the production of the various algae commodities (including high-value compounds) and ecosystem services (nutrient removal from waste streams, utilising CO_2 from flue gas) to maximise the socioeconomic potential of algae cultivation while offering the most likely scenario for producing algae biofuels economically. However, the scales required are difficult to reach within the near future. Many more pilot sites simulating large-scale cultivation conditions are needed to provide a foundation for technical and biological innovations as well as opportunities to generate data for techno-economical modelling. Whether results will subsequently meet expectations will depend on several factors, including breakthroughs in other energy sectors and the development of the whole production chain.

The opportunities in large-scale microalgae cultivation are global and the Baltic Sea Region is not likely to be the first place where it will take place as year round cultivation is not possible due to seasonal fluctuations of light availability and temperature. However, the region has a lot to offer for applied microalgae research based on its long tradition and high quality in aquatic sciences and energy technology developments. So far activities are still somewhat scattered and unfocused. In order to increase efficiency and thus speed up advances in this sector, coordinated action is necessary across the whole region which provides incentives for all key players – not only from research institutes but also private companies from the energy sector as well as water treatment or microalgae cultivation technology – to generate nodes of excellence and alliances in microalgae biofuel research.

Blue Biotechnology

Currently the application of biotechnology to marine resources is still at a nascent stage even on a global scale. However numerous forecasts predict major growth (e.g. 12 % annually for Europe) based on ever more rising consumer demand and correspondingly large markets for blue biotech products in the fields of medicine, cosmetics, food and feed supplements as well as environmental and industrial applications (pull-effect) coupled with the rapid increase of inventories of marine natural products and genes of commercial interest (push-effect).

In the Baltic Sea Region Blue Biotechnology has so far not played a major role even though its marine organisms provide a great potential for exploration, with the added advantage of easier and thus more cost-efficient access and clearer legal conditions. What is more: research centres already exist in almost all BSR countries with special expertise in all the different Blue Biotechnology fields as well as in the operation of necessary equipment for biotechnology. Some investment though is needed in order to develop sufficient upscaling of equipment and related quality assurance processes.

What is really missing, however, is a focused Baltic Sea wide strategy for the implementation of Blue Biotechnology, which is based on national strengths as well as the most urgent market needs within the Baltic Sea Region, all the while aligned with EU level developments. Based on such a strategy, regional disparities might also be turned into advantages, using laboratories in the eastern BSR while developing close links with the big pharmaceutical industry based more in the region's western parts. The ongoing success of the ScanBalt network for the last ten years has shown that the BSR is well placed not only to develop but also to implement such kind of strategy.

Wave Energy

Compared to e.g. wind or solar energy, wave energy is by its origin steadier and more predictable, as it can be available around the clock, day to day and season to season, thus having a higher utilisation factor and a higher power density. Various forecasts predict that wave energy is able to make a contribution of about 10 % of the world wide electricity consumption with corresponding investments of more than € 800 billion. It is foreseen that by 2050, 15 % of Europe's energy demand can eventually be covered by ocean energy resources with a total installed capacity of 188 GW. These projections are matched with substantial growth figures for the corresponding industry. By 2020 it is expected that 26,000 direct and 13,000 indirect jobs will have been generated by the ocean energy sector.

Technology is the crucial factor for wave energy development and much of this competence is actually based in those countries of the Baltic Sea Region which are also advanced in offshore wind technologies. This experience has so far, however, mainly been exported.

In the Baltic Sea itself hardly any testing has been undertaken to date. In comparison with other oceans and seas, the wave power density in the Baltic open sea is relatively low (compare: North Pacific 75 kW/m; Baltic Sea 2 kW/m). But also in the Baltic Sea the density can reach more than 50kW/m^2 at times of wind storms with the resulting wave energy being extensive especially in its eastern and south-central parts. One advantage of the Baltic Sea may also be smaller problems with fouling communities. Newly developed technical concepts, such as a small-scale, versatile, low-cost and high capacity linear generators, and proposed installation solutions may open opportunities for wave energy utilisation also in this region. In particular, combinations with offshore (wind) installations seem to be attractive both from an environmental and economic point of view. Should the Baltic Sea Region focus research on small-scale project opportunities in relatively low energy basins, it might not only develop into a model region in this field, but may also lead to the break-through of such systems world-wide.

Sustainable Fish Aquaculture

Aquaculture is globally the fastest growing food production sector (8.8 % yearly growth rate), but it is also linked to a number of environmental challenges. These include negative impact on water quality arising from fish effluent, the interaction with the natural populations, the use of wild fish population as fish feed as well as the amount of land, water and energy used.

Aquaculture in the Baltic Sea is almost exclusively based in Scandinavian countries. Contrary to global developments it is has constantly been on the decline from an already very low level representing only 0.1 % of world-wide aquaculture production (+6.9 % world-wide aquaculture growth since 2000 compared to -0.8 % BSR). This is due to limited amount of sites suitable for open net cage systems, which are still the predominant production technology, being the most cost-efficient (not accounting for environmental cost).

Innovative approaches are not only more sustainable, but also open the opportunity for the revival of this sector throughout the Baltic Sea Region.

Land-based recirculating aquaculture systems (RAS) are expensive to build as well as to run, but offer numerous advantages: heating can come from biogas plants; nutrient rich effluent water can be treated or used as a resource for greenhouses; production is year round and can also be used for new species and/or restocking purposes and natural systems are not impacted. What is more: since RAS can be placed in areas unsuitable for open net cage systems they offer new market opportunities for Baltic Sea countries, which have no aquaculture sector so far. The technology, know-how and a variety of companies for RAS plant construction and operation are all in place within the region, with Denmark being the forerunner in this market.

The addition of integrated multi-trophic aquaculture (IMTA) to existing open net cages is yet another opportunity to reduce environmental impacts through direct uptake of dissolved nutrients, while at the same time increasing cost-efficiencies due to more products which can be sold. So far, however, hardly any real data or practical knowledge is available as only a few pilots exist in Finland and Denmark, where mussel or macroalgae cultivations are combined with open net cage fish farms.

Combined Uses with Offshore Wind Parks

The potential area available for “combined uses” within offshore wind parks is estimated to be in the range of 850 km^2 by 2030 (compare: Annual harvesting of 140 km^2 of mussel farms would be sufficient to meet Sweden’s nitrogen reduction target from the Baltic Sea Action Plan) representing 25 % of the total space between individual wind mills in these parks. However, whereas planning for offshore wind is advanced, research on various forms of mariculture is lagging behind and even more so on combinations of those. With the exception of the Danish Rødsand II wind park, no practical pilot has ever been carried out throughout the Baltic Sea. As a result knowledge and real data are extremely limited even on world-wide scale. The development is also hampered by the lack of tradition and economic incentives (with the exception of possible image gains) for wind power companies to cooperate with the aquaculture sector.

Even less is known about wind-wave combinations. Using the same infrastructure for installation and energy transmission should be investigated very carefully as it seems to be an efficient way of increasing the utilization factor of sea space.

Whereas the concept of "spatial efficiency" promoting as much multi-uses as possible in order to leave as much space as possible free of use is very attractive at a theoretical level, practical evidence is missing. Thus political support is necessary to promote the set up of demonstration plants and pilot tests, which may hopefully provide convincing data with respect to positive environmental results, suitable technical solutions and economies of cooperation and scale. There is already a good level of communication between the various bodies dealing with maritime spatial planning within the Baltic Sea Region, providing a good basis for creating such cross-sectoral win-win situations.

Cross-cutting issues and conclusions

Microalgae cultivation for biofuel, blue biotechnology, wave energy and fish aquaculture are applications with global appeal. While the Baltic Sea resources may also be suitable for such applications to take place within the region itself, the Compendium also illustrates that the region exhibits also good conditions for becoming the knowledge and technology development hub in these sectors. In contrast, reed and macroalgae harvesting as well as mussel farming for other purposes than seafood derive their appeal from offering solutions with direct benefits for local communities in terms of environmental remediation and/or renewable energy resource.

Nevertheless, there is still a remarkably low level of awareness of the potential of the sea and its role for the economy and environment, with the majority of political strategies not taking the sea into due account.

These are, however, necessary as technological advances alone will not be sufficient to develop the full potential from Baltic marine resources. Technical innovations have to be coupled with innovative solutions in the underlying socio-economic, environmental, legal and political framework. Holistic, interdisciplinary approaches to analyse all – direct or indirect – effects of an application and its combination with others are required. Incentives to support public-private collaboration and create win-win solutions also between different applications have to be developed.

There are already a few good examples throughout the Baltic Sea Region, where scientists have worked together with public or private local decision-makers to turn one or more SUBMARINER applications into a viable business and/or public service model. In all cases, however, the need for more pilot sites to develop "known practice", real data as well as success stories has been stressed.

Finally, an overarching theme is the need for the development of a focused strategy for the Baltic Sea Region. This should take into account the specific qualities, characteristics and strengths of the region in general, as well as in each discipline and country, and be implemented within the collaborative structure of a transnational, cross-sectoral SUBMARINER Network.

About this Compendium

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The Baltic Sea – a (re)source of innovation

Oceans cover more than two thirds of the earth's surface and are of utmost importance for the health of both marine and terrestrial environments. At the same time, they host a vast diversity of marine resources, of which many are still untapped. Novel technologies and growing knowledge about new uses of these resources can generate great opportunities for innovation and significantly contribute to mitigate environmental problems.

Also the Baltic Sea represents a huge source of innovation. Despite the fact that its resources are already heavily exploited, new approaches towards their utilisation have the power to proactively improve the state of the Baltic Sea's vulnerable ecosystem and to contribute to the Baltic Sea Region's long-term economic prosperity. What has so far been missing, however, is a comprehensive far-sighted strategy towards the sustainable use of Baltic marine resources.

While there is no lack of ideas for innovative uses of Baltic Sea resources, there has so far no attempt been made to analyse them in a systematic way in order to provide a full picture of their true potentials within the Baltic Sea Region context.

This Compendium is designed in order to fill this gap. Its intention is to provide readers with objective information on the different properties of sea uses and the potentials deriving from them. It shall serve as a reference document on innovative uses throughout the Baltic Sea Region and beyond.

SUBMARINER Topics

Macroalgae Harvesting and Cultivation: Free floating or beach cast macroalgae can be collected to support water quality, nutrient recycling and biogas production. They can also be cultivated in nearshore installations.

Mussel Cultivation: Nearshore mussel farms may support water quality and nutrient recycling and offer valuable feed stuff.

Reed Harvesting: Removing reed from nearshore reed beds can support nutrient removal and bioenergy production.

Large-Scale Microalgae Cultivation: Cultivating microalgae for biofuel can be carried out in land-based cultivation systems and coupled with CO_2 and nutrient-rich waste water streams.

Blue Biotechnology: By extracting valuable substances produced by marine micro- and macroorganisms, e.g. bioengineering, pharmaceutical, medical and cosmetic purposes can be supported in a sustainable manner.

Wave Energy: Developing novel wave energy devices may offer the Baltic Sea Region an additional alternative energy source.

Sustainable Fish Aquaculture: Through innovative and environmentally sound technologies, fish aquaculture may be expanded also in the Baltic Sea Region in order to meet the rising demand for seafood for human consumption.

Combinations with Offshore Wind Parks: The possibility of combining offshore wind farms with cultivation of e.g. macroalgae, mussels and fish is explored in order to use the space between the individual wind mills efficiently.

Selection Criteria for SUBMARINER Topics

Resources and applications assessed in SUBMARINER are not a 100 % match with the world-wide types of the sea exploitation as defined in the recent European Commission's Blue Growth Initiative[1] (see table 1). Actually, the selection criteria applied by SUBMARINER were more narrow:

- With its focus on **emerging and innovative** uses SUBMARINER has only looked into activities classified as being at growing or pre-development stage.
  This is why topics like shipping, oil and gas, tourism or coastal protection are not part of SUBMARINER;
- On the other hand, new types of applications of reed qualified to be assessed by SUBMARINER, even though reed has been used for centuries;
- A core criterion was that an application should have **both an environmental and an economic appeal** (see table 2 for an overview of potential benefits of the selected uses). Thus topics like cruise tourism, maritime monitoring or marine minerals mining have not been touched;
- Only applications have been selected which are truly making use of a **marine resource** rather than taking place within the maritime space;
- Obviously only applications which are **applicable and of relevance for the Baltic Sea** as such have been taking into account, thus for instance making a discussion of tidal energy superfluous;
- Applications should have reached a stage **beyond basic science**, i.e. where at least some practical experience already exists on global scale with competence matched at Baltic Sea region level;
- Emphasis was placed on those applications, which are not yet in the stage of development that private initiative alone is sufficient for their development; i.e. not necessarily requiring public investment but other forms of **incentives / actions**
- Last but not least – the selection has focused on those uses, which are not already covered by other large scale singular-topic based projects/initiatives yet. Offshore wind parks and takes offshore wind development, for instance, is taken as a given with SUBMARINER only dealing with combined uses.

What does the Compendium assess?

Based on the currently available knowledge, the Compendium is for each of the above-mentioned resources carrying out a sustainability assessment for the whole product chain:

- The state of development or implementation world-wide and in the Baltic Sea Region,
- The quantity and suitability of the environmental resources required,
- Availability of suitable technology for the Baltic Sea environment along the whole production chain,
- Available competence throughout the Baltic Sea Region,
- Environmental impacts, both supportive and not supportive,
- Economic implications,
- Political Strategies and regulatory framework,
- Interactions between uses, possible positive synergies as well as potential conflicts,
- Major knowledge gaps.

As a result of this, the Compendium also provides an overview on obstacles and limitations to more widespread adoption or expansion under current conditions as well as recommendations to address these obstacles.

For whom is the SUBMARINER Compendium?

The initiative to create SUBMARINER and to develop this Compendium is a response to a demand presented by a multitude of actors throughout the Baltic Sea Region and beyond:

- Maritime Spatial Planners throughout the Baltic Sea Region are witnessing a structural transformation of the sea's exploitation, realising that planning at sea is about much more than only shipping and fishing. But whereas new uses have started to appear, their spatial, economic, legal and other requirements have remained vague – making it difficult to take them adequately into consideration.
- Coastal regions like Schleswig-Holstein in Germany as well as municipalities like Trelleborg in Sweden or Lolland in Denmark have started to initiate structural, comprehensive development plans, in which they make best use of their existing resources. They have an interest to exchange best practices and to be part of a larger knowledge source.
- Environmental regulators need to consider to what extent each or combinations of these emerging uses make a positive contribution to environmental challenges or whether these are actually

Table 1: Maritime economic activities studied by development stage – based on size (2008 or latest available year), recent growth (average annual GDP growth last 5 available years) and potential (ranking 1–6 with 6 highest). Source: Blue Growth – Third Interim Report.[1]

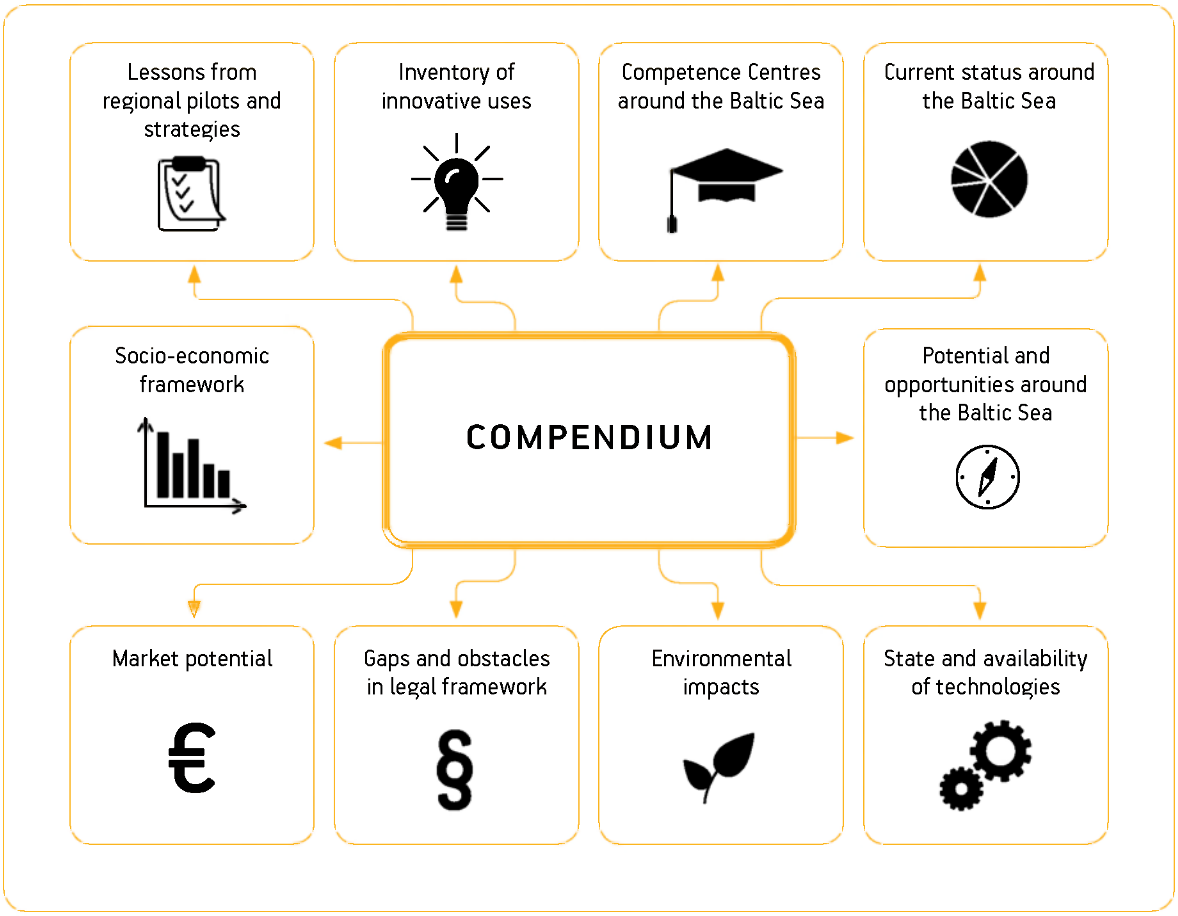
Maritime economic activity	**Size (bn €)**	**Recent growth**	**Potential**
Mature stage			
1. Shortsea shipping	63	6.1%	2
2. Offshore oil and gas	107–133	-4.8%	1
3. Coastline tourism & yachting	144	3-5%	4
4. Coastal protection	1.0-5.4	4.0%	6
Growth stage			
5. Offshore wind	2.478	21.7%	6
6. Cruise tourism	14.1	12.3%	5
7. Marine aquatic products	3.3	4.6%	4
8. Maritime monitoring and surveillance	1.8–2.3	+	5
(Pre-)development stage			
9. Blue Biotechnology	0.6–3.3	4.6%	5
10. Ocean renewable energy	<0.25	+	5
11. Marine minerals mining	<0.25	0/+	4

Table 2: Summary of the Potential Benefits of Various New Uses of Marine Resources in the Baltic Sea Region.

	Water quality & nutrient recycling	**Renewable energy**	**Biodiversity**	**Societal: health / food**	**Spatial efficiency**	**Economic**
Macroalgae Harvesting	●	○				○
Macroalgae Cultivation	●	○	○			○
Mussel Cultivation	●	○	○	○		○
Reed Harvesting	●	○	○			○
Microalgae Cultivation	●	●			●	○
Blue Biotechnology	●			●		○
Wave Energy		●				○
Sustainable Fish aquaculture (inc. IMTA)	○		○	●	●	○
Combined Use Wind Farms	●	○			●	○

● main benefit
○ by-product of main benefit but not sustainable on its own

Figure 1: Areas assessed in the SUBMARINER Compendium.



outweighed by other impacts. Given the little existing practical experience it requires as much pooling of expertise throughout the Baltic Sea Region as possible.

- Some excellent research is undertaken throughout the Baltic Sea Region on emerging uses, but there is a need for a more structural approach to interdisciplinary networking and competence clustering.
- Last but not least – innovators as well as investors, regardless of whether from the private or public domain – have prior to SUBMARINER been hampered by the lack of a common reference point.

SUBMARINER is based on the understanding that there are many "unknowns" in relation to these new marine uses and that thus some may never turn into reality but remain at visionary stage. But – first of all – it understands the topics selected under SUBMARINER as opportunities to foster the sustainable development of the Baltic Sea Region.

If the SUBMARINER Compendium can guide the Baltic Sea Region community towards the future development of those uses, which may actively contribute positively to achieving a good environmental status as well as leading to economic and employment growth throughout the region – it surely has achieved its purpose.

OTHER SUBMARINER ACTIVITIES

Besides the production of this Compendium, the SUBMARINER project is implementing the following activities:

- **Development of a roadmap:** recommending necessary steps across all disciplines to promote beneficial uses and mitigate against negative impacts, suggesting research topics, institutional and network initiatives, legal changes (e.g. spatial plans), environmental regulations and/or economic incentives.
- **Implementation of regional pilot activities:** testing new uses in real conditions, conducting feasibility studies for new uses in specific areas, assessing technological and financial needs, estimating impacts on environmental and socieconomic conditions or developing specific regional development plans.
- **Building a network:** creating a selfstanding, independent network for sustainable innovative marine uses and stimulating cooperation among relevant players through virtual and real networking, information exchange and cooperation events.

How this Compendium has been brought together

The Compendium is a joint output of all SUBMARINER project partners. Thus the inventory covers a range of different aspects for each resource or innovative use. On top it tries to cover this in reflection of all Baltic Sea Region EU member state countries.[1]

Its content is not only based on the project partners' own research or the experience gained in SUBMARINER regional pilots. On the contrary, the SUBMARINER Compendium tries to provide an overview of the current stage of knowledge and experience throughout the Baltic Sea Region based on the whole range of past or on-going projects, studies and pilot initiatives in the different spheres.

It is important to note that – with the exception of the SUBMARINER pilot cases – the content of the Compendium is based on external sources and/or studies undertaken by project partners previously (not for SUBMARINER purposes). The Compendium is therefore not based on a first hand survey or studies designed purely for SUBMARINER Compendium purposes.

In view of the importance attached to the environmental impacts of each of the uses a consistent methodology for environmental assessments was applied for each singular use (see extra box in this chapter).

For all other topics covered, the partnership has refrained from applying a unison methodology in view of the differences between the various applications and resources as well as the variety of reference points and background studies available. Measure units have been tried to be aligned as much as possible.

Even though the content of each of the chapters has been brought together under the leadership of one or two project partners, it tries to depict – as much as possible – an objective picture about the state of play for each of the topics covered. For this purpose each of the chapters has extensively been discussed among the whole partnership and also outside opinion has been brought in prior to publication. Whenever there is an ongoing debate about an issue, e.g. about certain environmental impacts of a use, it is clearly earmarked throughout the text.

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[1] Aspects from the Russian Federation have been tried to be reflected in the natural science part of the Compendium, but are not reflected in any of the other chapters.

Some of the Compendium chapters are based on an individual – longer – report prepared by the coordinators for each single topic. Also separate reports are available for each of the SUBMARINER regional pilot cases, which are from time to time mentioned in this Compendium. All these reports are available for free download at the SUBMARINER website (www.submariner-project.eu) and are clearly under the authorship as indicated.

ENVIRONMENTAL ASSESSMENT

ENVIRONMENTAL PRIORITIES AND ASSESSMENT FRAMEWORK

The requirements of pertinent EU Directives and HELCOM were used to establish a framework for carrying out the SUBMARINER environmental assessments. Consideration has also given to the concept of *Ecosystem Services*[2,3,4] in this process. A shortlist of fourteen environmental priorities organised under four broad environmental objectives were identified as being directly relevant to SUBMARINER. These are used to guide the environmental assessments.

1. **Water Quality**
   - i. Improve Bathing Quality
   - ii. Improve Water Transparency
   - iii. Decrease Eutrophication
   - iv. Maintain Stable Biogeochemical Cycling
2. **Habitat / Species Protection**
   - v. Maintain Food Web Dynamics
   - vi. Promote Biodiversity
   - vii. Protect Benthic Habitats
   - viii. Protect Bird Habitats
   - ix. Protect Fish Populations
   - x. Protect Marine Mammals
   - xi. Minimise Marine Noise
3. **Coastal Protection**
   - xii. Protect Coastal Morphology
   - xiii. Preserve Scenery
4. **Climate Protection**
   - xiv. Reduction of CO_2 emissions

It should be noted that each new use environmental assessment is dependent on location and specifics will vary regionally. The type of technology being used will play a critical role in the assessment, as will the time of year the activity is to take place, in particular for harvesting activities. These issues are addressed in detail in the individual assessments provided in the resource chapters that follow.

References

1 Ecorys, Deltares, Oceanic Development 2012: Blue Growth. Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts. Third Interim Report.

2 Millenium Ecosystem Assessment 2003: Ecosystems and Human Wellbeing: A Framework for Assessment. Chapter 2: Ecosystems and Their Services.http://www.maweb.org/en/Framework.aspx

3 Garpe, K. 2008: Ecosystem services provided by the Baltic Sea and Skagerrak. Swedish Environmental Protection Agency, Report 5873.

4 HELCOM 2010: Ecosystem Health of the Baltic Sea 2003–2007: HELCOM Initial Holistic Assessment. Baltic Sea Environment Proceedings No. 122.

Background: The Baltic Sea Region

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Delimitation of the Baltic Sea Region

There is no commonly accepted definition of the Baltic Sea Region. Its practical delimitation is based on functional relations, intensity of cooperation and interactions, as well as the nature of the problems requiring joint transnational action. Defining criteria may vary depending on the organisations and their purposes: they may be natural criteria such as catchment area (e.g. used by HELCOM), socioeconomic ones like the intensity of trade or migration, administrative or political ones such as membership in Baltic organisations (e.g. used by the Baltic Development Forum, the Council of the Baltic Sea States or the Baltic Sea Region Programme), spatial ones (e.g. used by VASAB) or cultural, historical and ethnic criteria like self-determination or common culture or values.

Despite different perspectives on its identity, the Baltic Sea Region is regarded as a well established functional macro-region unified by a unique historical experience and a dense horizontal cooperation network. A strong regionalism has evolved and has found its expression in the EU Strategy for the Baltic Sea Region (EUSBSR).

Economic links are not considered a key factor in the formation of the Baltic Sea Region as a functional entity. It was actually political will that, to a large extent, led to the transformation of the Baltic Sea Region concept into a reality during the 1990s. Important driving forces behind those political decisions were the cultural self-identification and joint historical experience (e.g. the creation of the Hanseatic League in the medieval ages or the Scandinavian cooperation, so intensely pursued in the 20th century) as well as the state of the environment of the Baltic Sea itself, which is a concern to all its bordering countries.[1]

THE SUBMARINER DELIMITATION

In the SUBMARINER project the sea area analysed encompasses the Baltic Sea, the Belt Sea, the Sound and Kattegat. From a political and socioeconomic perspective, analyses focus as much as possible on coastal regions, including the northern German states of Mecklenburg-Vorpommern and Schleswig-Holstein or the northern Polish regions of Pomorskie, Warmińsko-Mazurskie and Zachodnio-Pomorskie. Whereas analysis of natural resources took Russia into account, only the political strategies and legal frameworks of EU Member States were considered.

Unique Environment

The Baltic Sea is a unique environment in the world and one of largest semi-enclosed bodies of brackish water. Its shape, location and history have crucially influenced its present hydrological and biological features, in turn making it very sensitive to pollution and overuse.

Geographically it is a longitudinally stretched sea, divided into sub-basins with specific conditions, a diverse coastline and plenty of islands. It is almost entirely land-locked (surrounded by nine countries) with very limited water exchange with the ocean via Kattegat and the Danish Straits and with great riverine input. As a result, the water residence time is typically 25–30 years.

Compared to many other coastal areas, the Baltic Sea is almost entirely lacking recurrent tides. In Kattegat, the tide is normally about 5 cm and during special conditions temporarily reaches 20 cm. In the inner part of the Baltic, the tide is insignificant.

SALINITY

The main feature resulting from the Baltic shape and localisation is its low salinity: there is very limited saltwater inflow from the North Sea and a substantial amount of freshwater input from major rivers as well as hundreds of small catchments draining into

Figure 1: Different delimitations of the Baltic Sea Region.

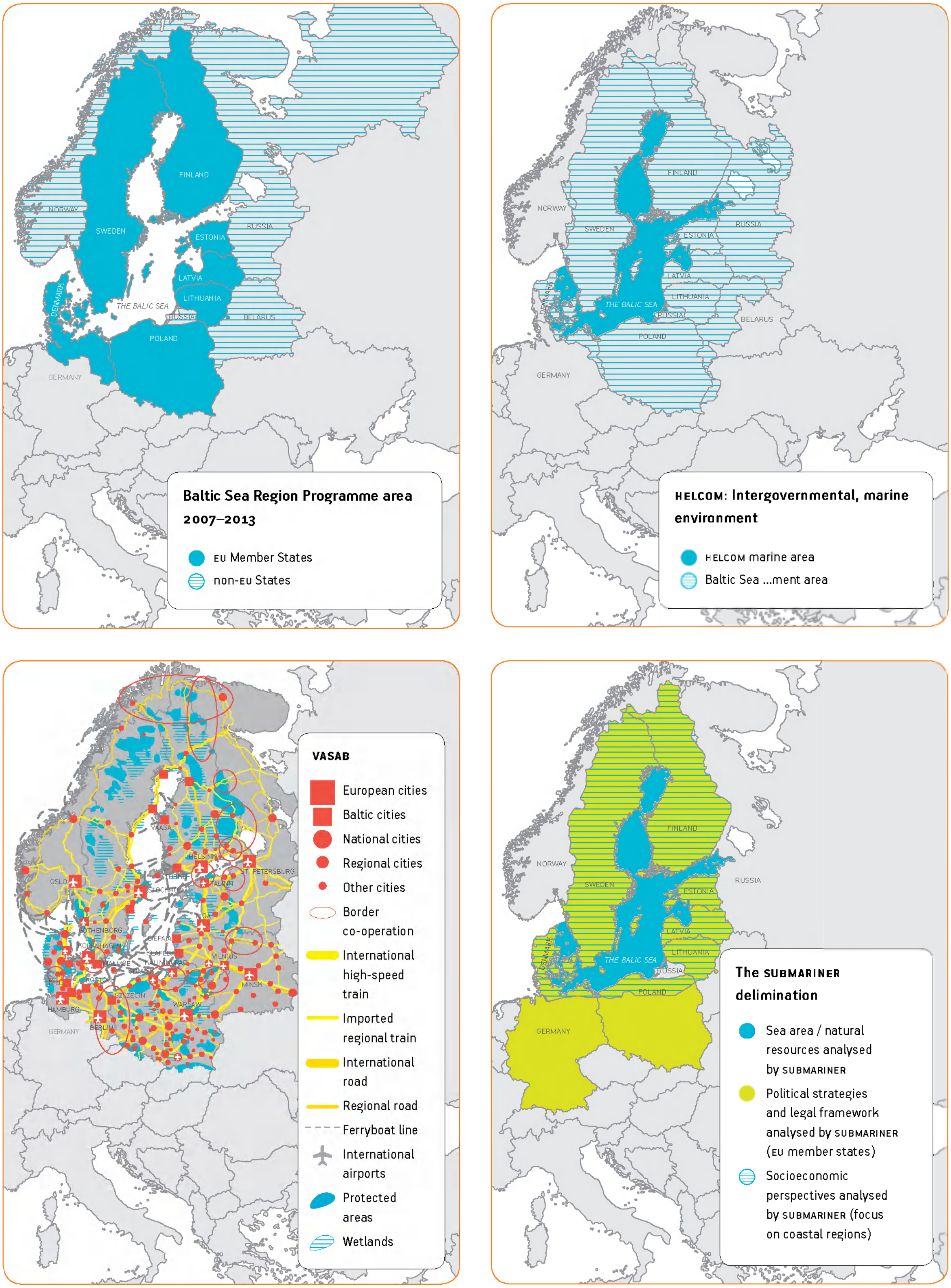
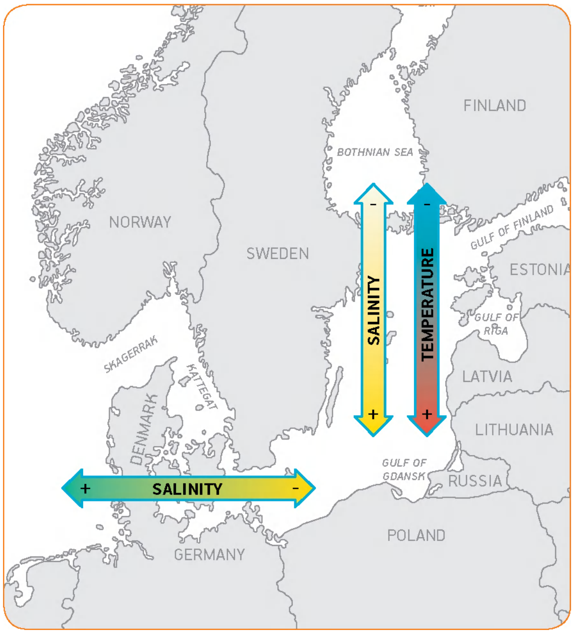


Figure 2: Salinity and temperature gradients in the Baltic Sea.

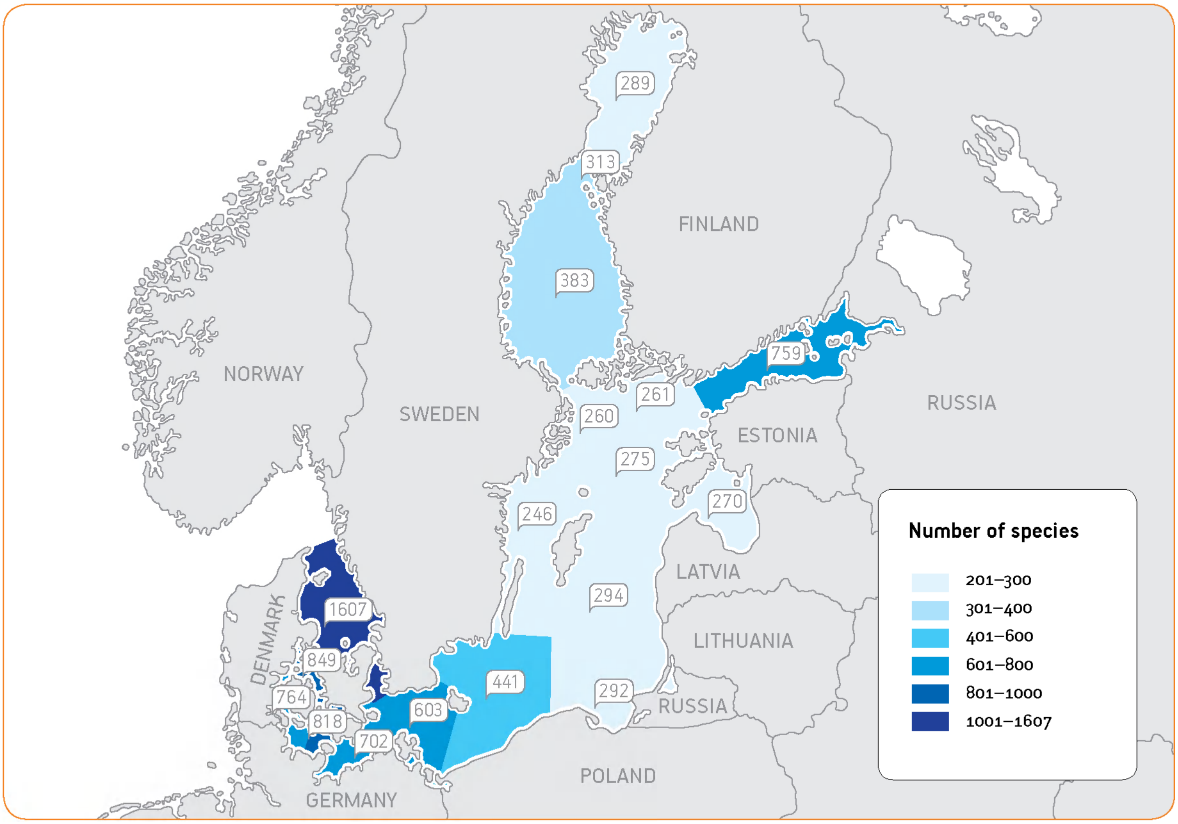


the Baltic Sea (figure 2). There is also a strong gradient in surface water salinity from almost 0 PSU in the north to over 20 PSU near the Kattegat and Danish Straits. Salinity levels also vary with depth, increasing from the surface down to the sea floor. Strong stratification, known as a halocline, occurs between 80 and 100 m, where fresh water lies above deep saline water masses. These saline water masses can experience long periods of stagnation, resulting in persistent anoxic conditions. The climate also supports the overall low salinity phenomenon as the rainfall volume predominates over the evaporation process in the region.

CLIMATE AND TEMPERATURE

Due to its longitudinal position, the region extends over two climatic zones: the north and northeast have a humid, sub-polar climate with mostly boreal forest, while the south and southwest have an oce-

Figure 3: Total number of Baltic Sea species (without bacteria) per sub-basin. Source: HELCOM.



anic, temperate climate and productive soils that support intensive agriculture. Snow cover duration ranges from 1 month in the south to 6 in the north.[1] The annual temperature variation in Baltic surface waters is great, ranging from below 0° C up to above 20° C in the summer. Ice formation also varies spatially: ice appears in the northern archipelagos in the Bay of Bothnia in mid November and in December in the southern Baltic. The sea is usually free from ice latest in May. In summer a *thermocline* divides surface waters into two layers: a wind-mixed surface layer down to a depth of 10–25 m and a deeper, denser and colder layer extending down to the sea-bed or the halocline.

BIODIVERSITY

The Baltic Sea ecosystem is relatively young, with an "ecological age" of only about 8,000 years.[2] This is reflected in the ongoing evolutionary process by the limited number of endemic species and simple trophic chains.

Salinity is the most important factor to influence aquatic life in the Baltic Sea. As it creates a stressful environment for many aquatic organisms, it is the primary reason for low Baltic biodiversity. Both freshwater and saltwater Baltic species have adapted to these suboptimal conditions, so that many of them are genetically distinct from their marine or freshwater source populations (e.g. Baltic cod). The number of species decreases with salinity from the west coasts to the inner parts of the Baltic Sea.

On the sub-regional and local scale the diversity is influenced by the type of substrate, coastline and light penetration. Within each sub-basin, salinity, nutrients and temperature are important factors affecting the temporal variation in diversity, particularly in the littoral and pelagic communities that undergo a pronounced seasonal succession.[3]

Economics

The Baltic Sea Region as defined in this report is inhabited by 52.2 million citizens (EU–27: 502 million). It has a GDP production of over € 1,025 billion (PPP adjusted), which constitutes 9% of the EU–27 economy (figures for 2011).

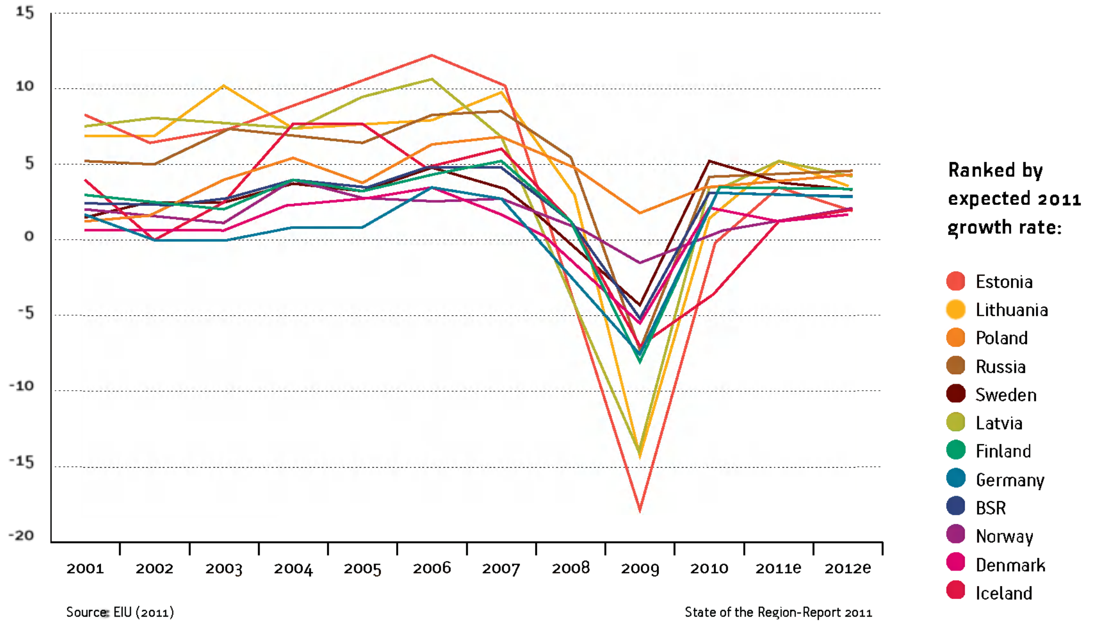
According to the VASAB Long Term Perspective (2009), three divisions can be seen in the Baltic Sea Region:

- The *east-west divide* – the former iron curtain – now reflects differences in prosperity and innovation performance.
- The *north-south divide* results from different climate conditions and is reflected in population density and related density of infrastructure.

Table 1: Size of the BSR economies and prosperity level in 2011 (GDP figures converted from US-$).

Country	**GDP (PPP)**		**GDP/capita (PPP)**	
	in billion €	**Rank in the world**	**in billion €**	**Rank in the world**
Germany	2,379	6	29.22	28
Russia	1,830	7	12.88	70
Poland	590	21	15.50	63
Sweden	293	34	31.31	20
Denmark	161	54	31	22
Finland	151	56	29.54	25
Lithuania	47	88	14.42	66
Latvia	25	105	11.88	79
Estonia	21	111	15.58	62

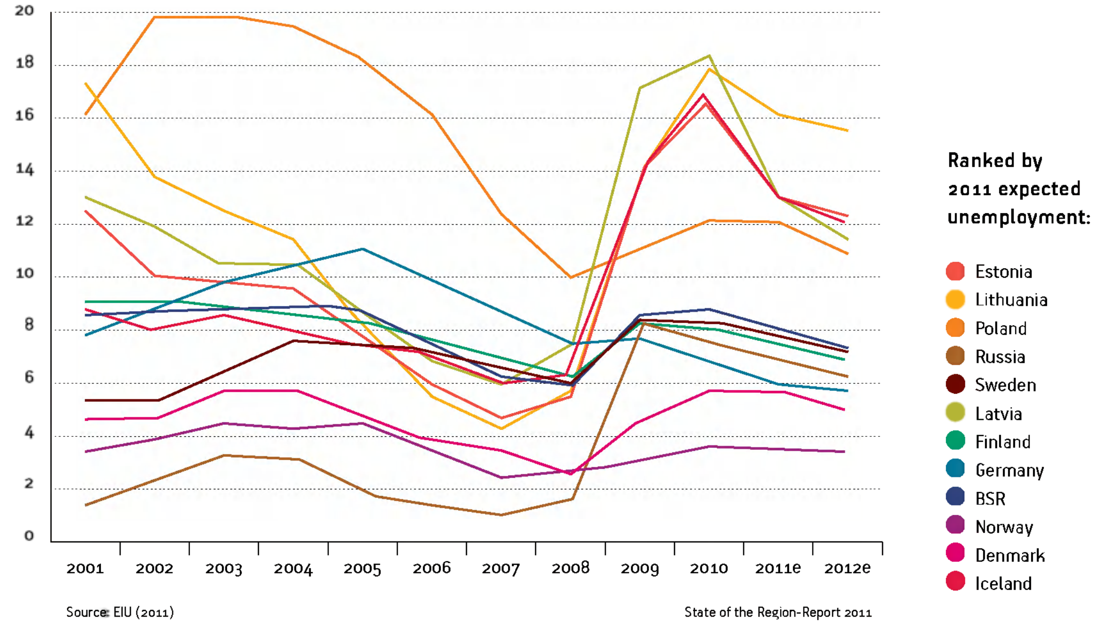
Figure 4: Economic growth of the Baltic Sea Region countries 2001–2012. Source: BDF State of the Region Report 2011.[4]



Source: EIU (2011)

State of the Region-Report 2011

Figure 5: Unemployment rates in the Baltic Sea Region countries from 2001–2012. Source: BDF State of the Region Report 2011.[4]



Source: EIU (2011)

State of the Region-Report 2011

- The *urban-rural divide* reflects different developmental perspectives and the importance of economies of agglomeration, resulting in differences in unemployment structure, age structure and migration patterns.

Further, another division can be drawn between small and large countries/economies (table 1).

Until 2008 the rate of GDP growth in the region outpaced the rates of regions such as North America or Western Europe. This growth is driven more by domestic demand than elsewhere in Europe, a pattern opposite to the rest of EU-27. The Baltic Sea Region also recovered quickly after the global crisis of 2009,[4] outpacing the EU-15 and NAFTA regions. Similarly, in terms of government debt, the Baltic Sea Region continues to outperform its peers, showing lower and slower growth rates in public debt levels than the rest of Europe.

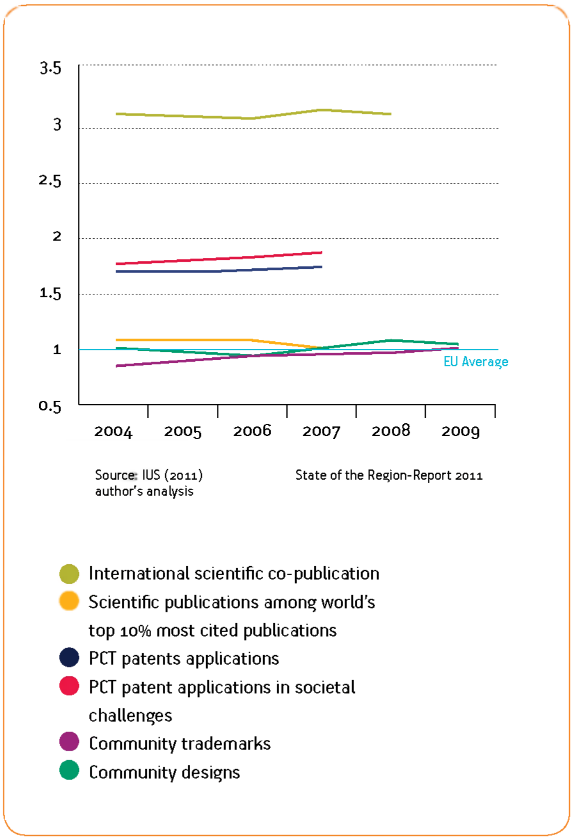
As a consequence of the current economic slowdown the growth pattern in the region seems to have changed. Whereas before 2009 the difference between some Baltic Sea Region countries was as high as 8 percentage points, current GDP growth rates have by now converged to between 1.6–4.2% among all Baltic Sea Region countries (figure 4).

A key challenge for the long term development of the region are the high unemployment rates, which have a negative bias towards the eastern part of the Baltic Sea Region (figure 5). Although the unemployment rate has recently been decreasing in almost all Baltic Sea Region countries, part of this success, at least in the Baltic countries, is due to outmigration.[4]

A European Leader in Innovation?

The Baltic Sea Region's scores with regard to the number of scientific publications and patents are reported to be above the EU average (figure 6). However, the low level of trademarks and designs seems to indicate a weakness in translating those assets into the region's welfare.

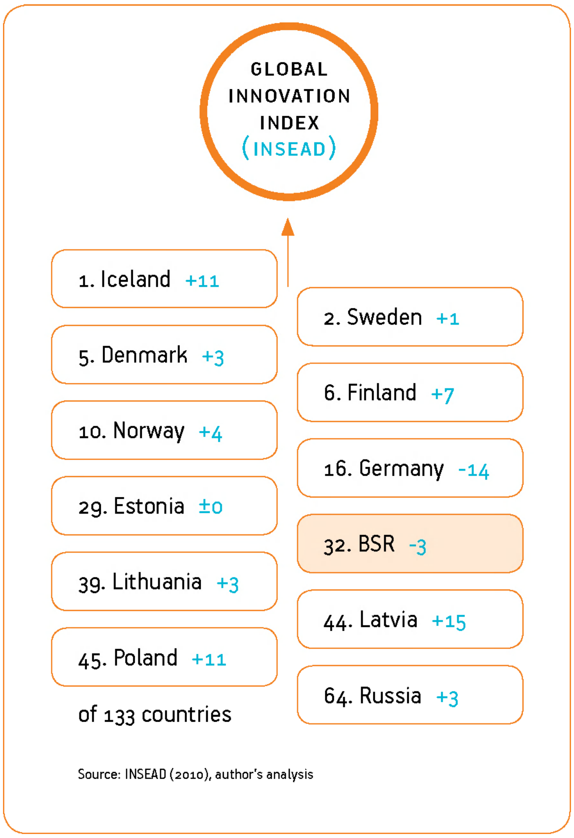
Figure 6: Baltic Sea Region innovation indicators from 2004–2009. Source: BDF State of the Region Report 2011.[4]



However, it has to be noted that the lion's share of the region's extraordinary position as an innovation leader is due to the strong scientific capability of Germany and the Nordic countries. Different innovation rankings reveal a substantial heterogeneity of innovativeness performance among the various Baltic Sea Region countries (figure 7).

These differences are reflected in the structure and composition of the Baltic Sea Region economies. Agriculture remains important in Poland, Russia and the Baltic countries. The service sector is largest in Latvia, Denmark and Sweden. The industry share is highest in Norway and Russia, among others, due to well developed mining sectors. The highest share of manufacturing in GDP has been registered in Poland.[4]

Figure 7: Different innovation rankings for the various Baltic Sea Region countries in 2010. Source: BDF State of the Region Report 2011.[4]



Source: INSEAD (2010), author's analysis

Maritime Economy: A Prospective Future in Blue Growth?

Figures for the Gross Value Added (GVA) of maritime economic activities for the EU are positive ranging from € 187–495 billion with a contribution of 4.8–5.6 million jobs. The exact figures vary due to differing timing, maritime activities included and methodology used of the respective studies.[5] At the same time they also show, however, that the importance of the maritime economy for at least half of the Baltic Sea Region countries is still limited (figure 8). Only in Latvia, Estonia and Denmark does the share of the maritime economy in the GDP exceed 4 % and 5 % of employment. For the other Baltic Sea Region countries those shares are below 2.6 % and 3 % accordingly.[5]

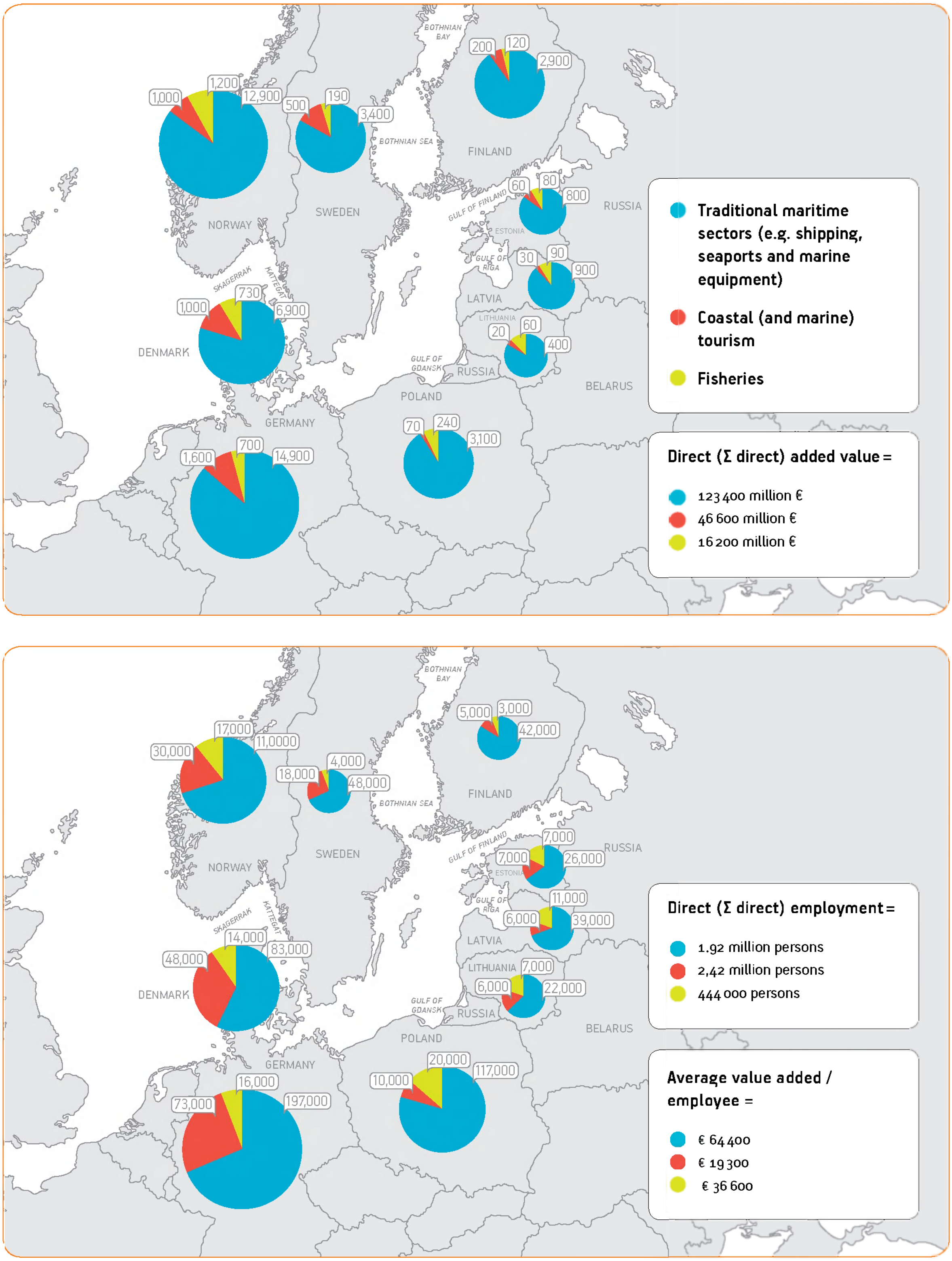
The Baltic Sea Region countries differ in the structure and composition of their maritime economies. For the western and the northern coastal regions, shipping and ports are the main sources of maritime income (figure 9). In the eastern Baltic countries and Poland fishery plays a more significant role in the maritime economy (mainly in relation to employment) than in the western and northern regions. Tourism – including cruises and coastal tourism – is also of importance, and particularly in the west and northern Baltic, even more so than the fisheries sector.

Even though the maritime sector plays only a limited role in the Baltic Sea Region's economy as a whole, it naturally gains more importance when focusing only on its coastal regions. An example can be seen in the German state of Schleswig Holstein, which introduced Blue Growth as a developmental driver in its medium term development strategy. The Pomorskie Region in Poland also focuses on the importance of sea-related innovations in its brand new development strategy of 2012.

So what lies in store for the Baltic Sea Region's maritime economy in years to come? This is extremely difficult to predict. However, various recent surveys[9,10] predict the expansion of several maritime sectors in the region in the coming years. Fast development is expected in the wind energy sector, shipping, ports, minerals extraction, installation of new pipelines and cables, as well as tourism and recreation. According to the WWF the "Baltic Sea is facing an extensive expansion of human activities within the coming 20 years with a projected growth of several hundred percent for many sectors."[6] Similarly, the EU study on Blue Growth[7] identifies developmental trends for the Baltic Sea Region's maritime economy, also predicting growth in windfarm development (particularly in Denmark and Germany and a lower intensity in Latvia, Lithuania and Russia), coastal tourism and Blue Biotechnology.

Despite its still relatively minor role in the region's overall economy, the expected growth and increased competitivity of the maritime sector as well as its potential role in the development of a

Figure 8: Direct value added and employment figures for different maritime sectors.
Source: Policy Research Corporation.[5]



bioeconomy is the reason why it has become a key policy focus for the EU and Baltic Sea states. This is best reflected in the recent revision of the EU Baltic Sea Region Strategy, which presents an integrated framework to address the challenges and opportunities of the Baltic, including those of the maritime sector.

Policy Framework

One of the key features of the Baltic Sea Region is its long-standing tradition of transnational cooperation, which is evidenced by the great number of transnational organisations and networks, especially in relation to maritime affairs. The Council of the Baltic Sea States, HELCOM, VASAB, the Baltic Sea States Subregional Cooperation, the Conference of Peripheral Maritime Regions (CPMR) Baltic Sea Commission, the Baltic Sea Parliamentary Conference, the Baltic Development Forum or the Baltic Sea Forum are just a few of the transnational actors actively involved in shaping the future of the Baltic Sea.

Many of these organisations have elaborated strategies, action plans and visions, covering a wide range of aspects from socioeconomic to environmental issues for both land and marine territories. All of them have the ambition of creating a development path or vision as well as setting out a range of general policy principles, priorities and specific targets for the Baltic Sea Region.[8] They are not merely a response to external policy drivers, they are often the driving force helping set the desired directions to be followed and objectives to be achieved at EU level and actively shaping EU policy development for the region.

The adoption of the European Union Strategy for the Baltic Sea Region (EUSBSR) in 2009 marked a corner stone in trying to provide an integrated strategic framework for the huge variety of actors,

Table 2: Main strategic documents that are likely to influence development of the Baltic Sea Region in the next 20 years.

International Policy Documents

- UNFCCC and Kyoto Protocol
- Europe 2020: A Strategy for Sustainable Growth and Jobs
- Energy 2020: A Strategy for competitive, sustainable and secure energy
- EU Strategy for Biofuels (COM(2006) 34 final)
- EU Strategy for a Bioeconomy in Europe (COM(2012) 60 final)
- EU Integrated Maritime Policy (covering Maritime Spatial Planning and Blue Growth)
- EU TEN Network (transport, energy, telecommunications)
- EU Communication on Adapting to climate change
- EU Common Fisheries Policy

EU STRATEGY FOR THE BALTIC SEA REGION

- Save the sea
- Connect the region
- Increase prosperity

'Visions' for the Baltic Sea

- HELCOM Baltic Sea Action Plan
- Baltic Development Forum: Going for Green Growth in the Baltic Sea
- VASAB Long Term Perspective
- Baltic 21 Strategy (partly subsumed in VASAB long-term perspective)
- CBSS 2020

policies and funding mechanisms present in the region (table 2). The Strategy provides the link between the Baltic Sea Region and the European policy level, reflecting the Europe 2020 objectives of smart, sustainable and inclusive growth and evolving EU policy developments. In fact, the macro-regional approach seems to offer the appropriate level for challenges too broad for the national but too specific for the EU-27 levels.

To give the strategy more focus and direction, the following three overall objectives were introduced in the revised EUSBSR of 2012: 1) Save the sea, 2) Connect the region and 3) Increase prosperity.

The main concern behind the formulation of ecological priorities or targets is the actual or potential deterioration of the marine environment, with the potential worsening effects caused by climate change. Specific emphasis is given to pollution and eutrophication, the loss of biodiversity and increasing pressure from a widening range of marine activities. On a socioeconomic front, overcoming east-west divides and social and economic disparities and thus enhancing territorial cohesion is the key objective, which hinges on stimulating economic growth, providing access to markets and the necessary infrastructure (e.g. transport). While EU policy places a particularly strong focus on this, it is made clear that this is not to be achieved at the expense of the environment. All of these can be considered long-term drivers that are likely to remain in place as a general framework for future developments in the Baltic Sea Region.

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

THE HELSINKI CONVENTION

The Convention on the Protection of the Marine Environment of the Baltic Sea Area from 1992, known as the Helsinki Convention, provides a basis for environmental protection measures by the Baltic Sea countries and the EU. It can be viewed as the most important international instrument addressing nature and environmental protection among those EU member and non-member States bordering the Baltic Sea.

While HELCOM's recommendations are not binding in terms of international law, they are of political and moral significance. They can be thought of as minimum standards that have to be implemented in the contracting parties' national legislation.

Among these recommendations, contracting parties are expected to apply the precautionary principle, ensure Best Environmental Practice and Best Available Technology and apply the polluter-pays principle. Parties are also expected to prevent and eliminate pollution derived from harmful substances coming from all sources and to ensure that adequate preparedness is maintained for immediate response actions against pollution incidents. The Helsinki Convention also addresses nature conservation and biodiversity, suggesting that appropriate measures be taken to conserve Baltic natural habitats and biological diversity and to protect ecological processes.

In 2007, HELCOM produced the new Baltic Sea Action Plan (BSAP), a plan different from any previously undertaken in its approach, which is based on a clear set of ecological objectives defined to reflect a jointly agreed vision of "a healthy marine environment, with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable human activities". For example, the BSAP determines that in order to achieve "clear water" – one of its main objectives – phosphorous and nitrogen inputs to the Baltic Sea must be further cut by about 42 % and 18 %, respectively and then sets out reduction targets for every country based on their inputs. While not legally binding, the Plan was developed through stakeholder participation and is considered a joint regional policy, with common objectives, actions, and obligations.

Regulatory Framework

When considering potential marine uses in the Baltic Sea Region, it is necessary to survey the underlying international regulatory framework providing the basis for their implementation. The relationship between international, European and national legislation can be complex, as many layers are involved:

- Based on its institutional powers, the European Community has adopted various international treaties addressing environmental protection. Generally, these agreements are mixed agreements, engaging both the Community and the Member States and they are legally binding. An example is the Convention on Biological Diversity (CBD). The European Union, a Contracting Party and an actor on a regional scale, has then implemented Art. 8 lit. h of the CBD along with the Council Regulation (EC) No. 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture. The regulation has its origin in international environmental law (CBD) and holds direct binding force for the Member States.
- This is in contrast with EU Directives. These represent the main legislative instrument concerning environmental protection but are binding only regarding the set aim and the Member State addressed. Here the Member States are obliged to choose the appropriate form and method to accomplish the goal (referred to as "graded binding nature") and they should implement it within national legislation. As a consequence, no overall Baltic Sea wide conclusion can be drawn for the approval processes relating to many of the SUBMARINER applications as it is up to each Member State or even lower (regional / municipal) levels to interpret the ways in which a specific aim is to be achieved.

Table 3: International regulatory framework for marine uses in the Baltic Sea Region: international conventions, European directives and recommendations.

<table>
<tr><th colspan="2">International Umbrella Convention</th></tr>
<tr><td rowspan="3">Effect has to be given in the States' national law in some form, must be declared applicable</td><td>United Nations Convention on the Law of the Sea (UNCLOS)
Aim: to define the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources.</td></tr>
<tr><td>United Nations Convention on Biological Diversity (UN/CBD)
Aim: to develop national strategies for the conservation and sustainable use of biological diversity.</td></tr>
<tr><td>United Nations Framework Convention on Climate Change (UNFCCC)
Aim: to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system</td></tr>
<tr><th colspan="2">Regional Sea Convention</th></tr>
<tr><td>"Soft law", rules of conduct for international practice, not legally binding</td><td>The Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM) (See box)
Aim: measures for the prevention and elimination of pollution of the Baltic Sea.</td></tr>
<tr><th colspan="2">EU Regulations</th></tr>
<tr><td>General application, binding in its entirety, directly applicable to the Member States</td><td>Regulation on alien species in aquaculture
Aim: to reduce the environmental risks derived from the introduction and translocation of non-native species in aquaculture</td></tr>
<tr><th colspan="2">EU Directives</th></tr>
<tr><td rowspan="9">Goal within directive is binding, Member States choose appropriate form of implementation ("graded binding nature")
Due to their binding nature, the targets set out can be expected to be strong drivers for years to come, requiring the support of a wide range of management measures.</td><td>EU Marine Strategy Framework Directive (2008/56/EC)
Aim: Good Environmental Status (GES) of the EU's marine waters by 2020</td></tr>
<tr><td>EU Water Framework Directive (2000/60/EC)
Aims: to protect all waters, surface waters and groundwater; achieving "good status" for all waters by 2015; water management based on river basins</td></tr>
<tr><td>EU Bathing Waters Directive (2006/7/EC)
Aim: to protect environmental quality and human health by complementing the Water Framework Directive</td></tr>
<tr><td>EU Urban Wastewater Directive (91/271/EEC)
Aim: to protect the environment from the adverse effects of urban waste water discharges and discharges from certain industrial sectors</td></tr>
<tr><td>EU Shellfish Directive (2006/113/EC)
Aim: concerns the quality of shellfish (bivalve and gasteropod molluscs) waters and applies to coastal and brackish waters</td></tr>
<tr><td>EU Habitats Directive and Natura 2000 (92/43/EEC)
Aim: coherent network "Natura 2000" of protected sites entitled "special areas of conservation"/"special protection areas"</td></tr>
<tr><td>EU Renewables Directive (2009/28/EC)
Aim: to establish a common framework for the promotion of energy from renewable sources</td></tr>
<tr><td>Environmental Impact Assessment Directive (2011/92/EU)
Aim: clarification of the environmental impact of public and private projects</td></tr>
<tr><td>Strategic Environmental Assessment (2001/42/EC) Directive
Aim: to provide for a high level of environmental protection with the adoption of plans and programmes (e. g. agriculture, energy) by an authority
EU Recommendations / EU Environmental Action Programmes</td></tr>
</table>

Key Environmental Challenges

The Baltic Sea ecosystem is fragile and particularly vulnerable to the effects of natural variability, human induced eutrophication, introduction of alien species, the input of organic pollutants and large-scale human disturbance, for example, ocean acidification and climate change. The Baltic Sea is severely affected by human impacts and only a few coastal areas along the Gulf of Bothnia can be considered as healthy.[9]

Nutrient Input and Eutrophication

The natural nutrient levels in the Baltic Sea have strongly increased during the last decades. Human induced eutrophication is a major problem in the Baltic Sea Region caused by excessive nitrogen and phosphorus loading from anthropogenic activities. Since the 1950s, the Baltic Sea has experienced a five – to tenfold increase in nutrient loads. Approximately 75% of the nitrogen load and at least 95% of the phosphorus load enter the Baltic Sea via rivers or as direct waterborne discharges (the remaining 25% of the nitrogen load comes as atmospheric deposition). Further, the largest sources of nutrients (at least 45% of the Baltic load) are diffuse sources, with agriculture contributing on average 60–70% of the reported total diffuse inputs to the sea. In 2008 the total waterborne nutrient input to the Baltic Sea was estimated to be 652,100 tonnes of nitrogen and 29,000 tonnes of phosphorus.[10]

Figure 9: Map of the Baltic Sea eutrophication based on HELCOM's Eutrophication Assessment Tool (HEAT). A total of 189 "areas" (a mix of stations, sites and basins) are classified as either affected by eutrophication (moderate, poor or bad status) or not affected by eutrophication (high or good status).

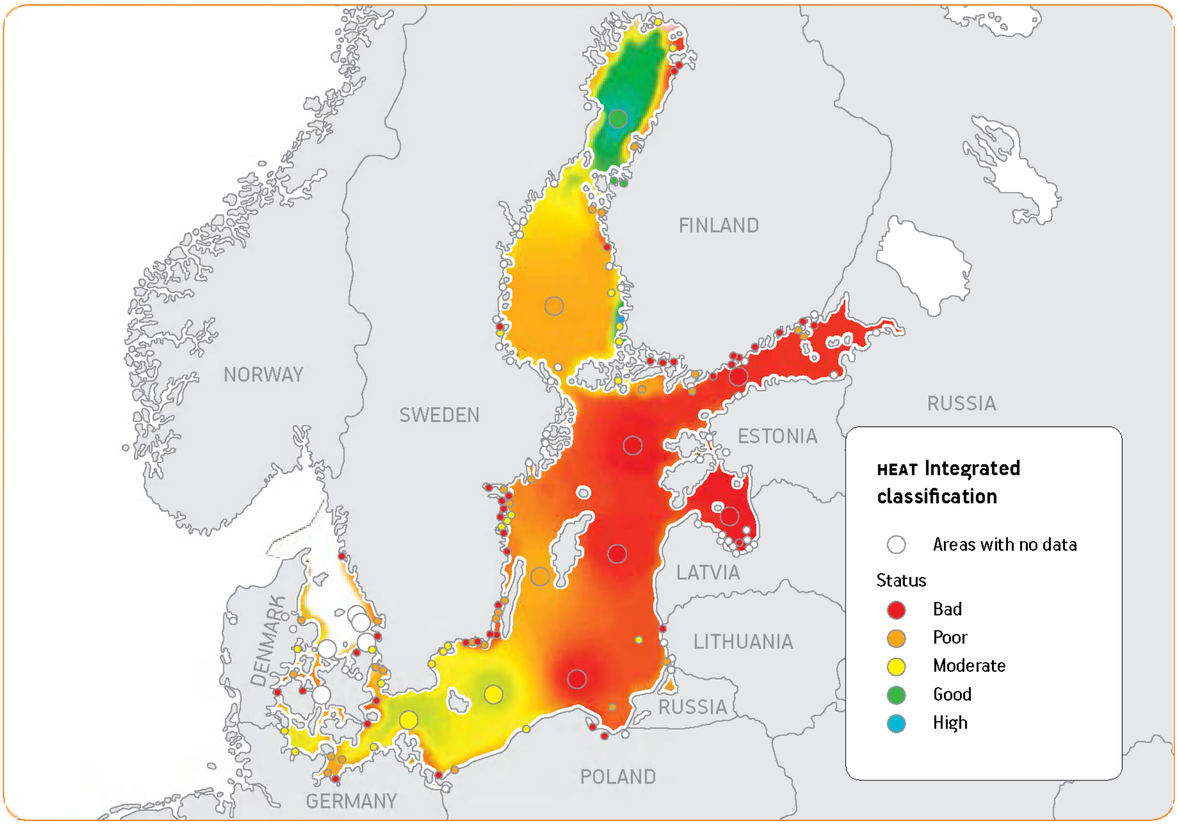


Table 4: Country-wise nutrient loads and reduction targets according to HELCOM Baltic Sea Action Plan.[9]

	Loads to basins with a reduction need (average 1997–2003)		Country reduction targets		Percentage country reduction targets	
	Nitrogen (tonnes)	Phosphorous (tonnes)	Nitrogen (tonnes)	Phosphorous (tonnes)	Nitrogen (%)	Phosphorous (%)
Germany	20,848	534	5,621	242	27	45
Denmark	57,501	51	17,207	16	30	31
Estonia	19,054	1,261	896	222	5	18
Finland	15,852	578	1,199	146	8	25
Lithuania	45,109	1,336	11,746	881	26	66
Latvia	10,447	1,613	2,561	300	25	19
Russia	89,386	6,683	6,967	2,500	8	37
Poland	215,350	13,717	62,395	8,755	29	64
Sweden	72,762	860	20,780	291	29	34
Total	546,309	26,633	129,372	13,353	24	50

Excessive nutrient loading, particularly in coastal waters leads to increased algae growth and increased frequency and magnitude of algal blooms. This excessive production of organic matter not only reduces water transparency but its sedimentation to the seabed and increased oxygen consumption lead to anoxic and hypoxic conditions, along with transformations in the nutrient flows, habitat loss, mortality of benthic organisms and impaired recruitment success of commercial fish.[11] While anoxic sea floors have been a natural feature of the Baltic Sea through geological time, their occurrence and extent have dramatically increased due to human activities.[12] As seen in figure 9 the most affected areas in terms of nutrient loading are the Gulf of Finland, the Northern Baltic proper, the Eastern Gotland Basin, the Gulf of Riga and the Belt Sea.

Extensive efforts are needed to combat the nutrient loading and eutrophication problem. Consequently, this issue has become a centrepiece of most of the region's political frameworks. The EU Strategy for the Baltic Sea Region has listed as its first of 15 priority areas the reduction of nutrient inputs to the sea, which it hopes to contribute to through a series of targeted actions and flagship projects. Some of these actions are described in HELCOM 's BSAP, which is an ambitious programme to restore the good ecological status of the Baltic marine environment by 2021. In its BSAP, HELCOM has shaped an ambitions pollution reduction scheme, determining the maximum allowable nutrient inputs and the difference between this level and the actual. Excessive inputs and reduction targets have been allocated to all the Baltic Sea Region countries (table 4). Even though technically speaking it is not legally binding (see box above), the BSAP reduction scheme is unique worldwide not only due to its advanced scientific foundation but mainly because for the first time ever the Baltic Sea countries accepted their share of the pollution in the form of concrete reduction targets.

The BSAP also lists examples of specific measures for reducing phosphorus and nitrogen losses from agriculture, including the following ones, which are of particular relevance to SUBMARINER project:

- Converting arable land to extensive grassland
- Planting cover in winter
- Spring cultivation
- Reducing fertilisation
- Composting solid manure
- Biogas production
- Establishment of wetlands
- Effective purification of runoff waters

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

Many of the innovative uses analysed by the SUBMARINER project such as macro – and microalgae cultivation, mussel cultivation or reed harvesting, were chosen due to their potential, if promoted to a larger scale of implementation, for making substantial contributions to nutrient removal and water quality improvement.

There are several methods of socio-economic valuation of ecosystem services. Large differences may occur not only depending on the method applied but also between regions since the value of good water quality or political goals may vary substantially.

The **“willingness to pay” method** applied by the Swedish Environmental Protection Agency for instance suggests a value of € 3.7 per kg for nitrogen and € 123.2 per kg for phosphorous reduction.[13]

The **“marginal cost” method** looks into what has been done before and extrapolates these costs in order to reach the political goal. With this method the value for nitrogen reduction increases to € 32.3 per kg and € 650 per kg for phosphorous respectively in the coastal area of the Swedish Baltic Proper.[14]

Climate Change

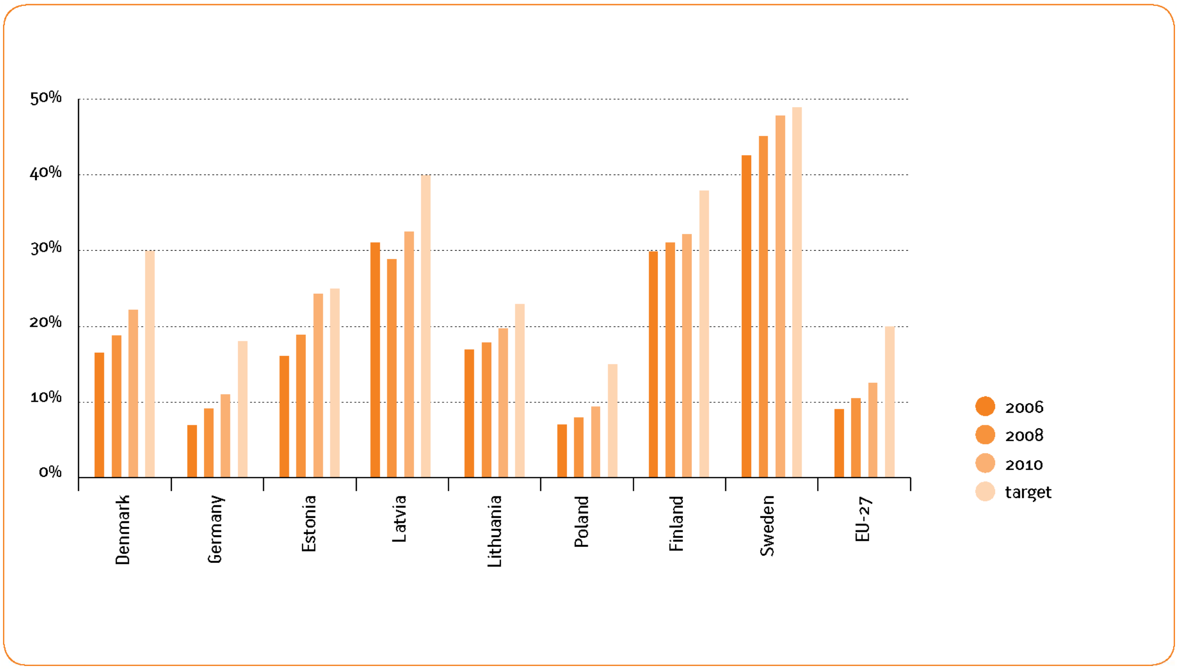
Climate change will impact the Baltic Sea Region’s environment and economies in many ways. The most relevant impacts of climate change on the atmosphere are expected to be increased air temperatures, increased precipitation, changes in wind regimes and more frequent extreme weather events. As far as the sea goes, climate change will lead to sea level rise, decreased ice cover, increased ocean temperatures and decreased salinity.[15]

The Baltic Sea Region is currently estimated to be a weak source of CO_2 to the atmosphere, with an annual contribution of – 1.05 Tg C ± 1.71[16]. Though the northern watersheds, forest dominated and sparsely populated, have been carbon and nutrient sinks since the last glaciations, climate change is projected to lead to pronounced increases in temperature and precipitation in these areas (increases of 2.6–5.1 °C and 13–33 % precipitation), altering their entire discharge patterns, significantly increasing runoff and extending spring flow duration. These watersheds will then effectively act as carbon and nutrient sources[17]. In the southern Baltic region, where coastal eutrophication has the biggest impact, projected increases in temperature and decreases in salinity[18] coupled with land use changes and new catchment management plans will all become factors that combine to determine the extent of climate change impacts[19].

CLIMATE CHANGE ADAPTATION

Climate change adaptation policies are generally still at an early stage of development. In addition to being subject to United Nations and European scale policies, the Baltic Sea Region’s climate change adaptation efforts are also guided by the EU Strategy for the Baltic Sea Region, in which climate change is one of the priority areas. A macro-regional climate change adaptation strategy for the Baltic Sea Region is currently being developed by the Baltadapt project (2010–2013), which will focus on coastal and marine issues and will make the Baltic Sea Region the first European macro-region with a climate change adaptation strategy. At a national level, adaptation

Figure 10: Share of renewable energy in the Baltic Sea Region countries' gross final energy consumption.[21]



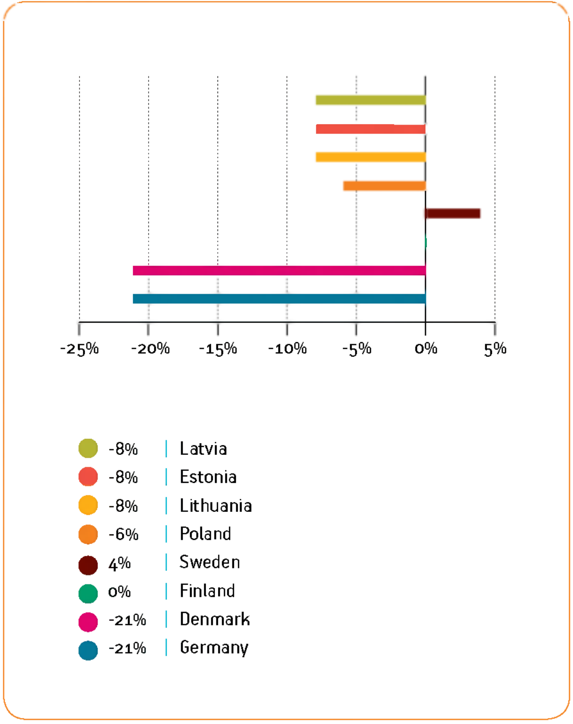
strategies are in place in Denmark, Finland and Germany, while Latvia and Lithuania are currently developing their own.

CLIMATE CHANGE MITIGATION

Climate change mitigation policies aim at limiting climate change by controlling the emission of greenhouse gases. The targets for reducing greenhouse gas emissions for mitigating climate change are set in the following policies:[20]

- Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), the EU-15 has committed itself to reduce its greenhouse gas emissions by 8% between 2008 and 2012. For most of the EU-12 countries, there are individual reduction targets. The reduction targets for the Baltic Sea Region countries are shown in figure 11.
- Looking beyond the commitment period of the Kyoto Protocol (2008–2012), the EU's Climate and Energy package commits the EU-27 to reduce its greenhouse gas emissions by at least 20% compared to 1990 by 2020 and to cover 20% of the

Figure 11: Greenhouse gas emission targets for the Baltic Sea Region countries under the Kyoto Protocol relative to base-year emissions.[22]



energy consumption with renewable resources in 2020. The share of renewable energy and the targets for the Baltic Sea Region countries are shown in figure 10.

- Although not containing any legally binding reduction targets, the 2009 Copenhagen Accord recognises the need for considerable emission reduction targets to limit the increase in global average temperature to below 2°C above pre-industrial levels. The EU-27 has submitted its conditional offer of a 30% reduction, if other developed countries commit to comparable emissions reductions.

New sources of biofuel and biogas will need to be explored which do not compete for land space with food crops and other land uses. In this regard, the production of biogas and biofuel from such renewable sources as macroalgae, microalgae or reed explored by the SUBMARINER project, have the potential to make a contribution to these targets goals at least at a local and regional level.

Table 5: Status of invasive species in the Baltic Sea in April 2012.[24]

Invasive Species Status in the Baltic Sea as of April 2012			
		Introduced by:	
Number of alien species found	119	Shipping	54
Number of established alien species	79	Stocking	43
Number of not established alien species	17	Ornamental	3
Number of alien species with unknown establishment status	23	Associated with aquaculture	12
		Unknown	10

Other Pressures

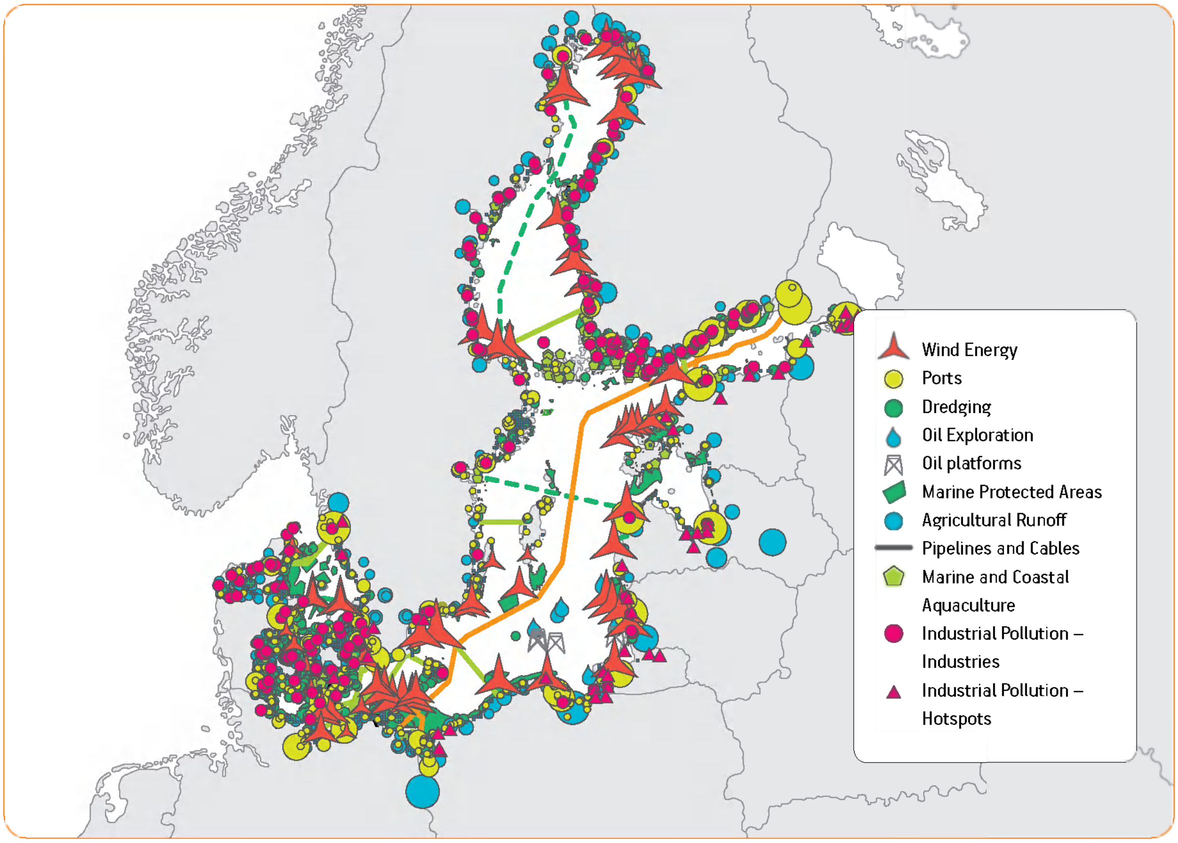
Pollutants are also important stress factors in the Baltic Sea, with negative impact on both flora and fauna.[9] Many of these chemical substances are either not naturally occurring in the environment or are natural substances that are occurring in higher concentrations than normal. Persistent chemicals are particularly troublesome since they can accumulate in the marine food web. Eating e.g. fish with high levels of toxic substances may also affect humans and thereby threaten the health of future generations. Industrial wastewater and municipal wastewater are the main pathways for pollutant introduction along with the shipping sector.

Another issue of concern to the marine environment are invasive species, which are considered the second leading cause of biodiversity loss after habitat alteration in the Baltic Sea.[23] Their ecological impacts are complex. They may lead to changes in resource competition (for food and space), changes in habitat (physical and biological), changes in the trophic web, production of toxins, introduction of new disease agents and parasites, genetic effects on native species and, as a worst-case scenario, extinction or drastic reduction of native species. The issue of invasive species is a topic of particular attention when conducting an Environmental Impact Assessment, especially for installation of any sort of aquaculture facility.

The Competition for Maritime Space

The Baltic Sea is becoming more and more crowded, used for a variety of maritime activities, almost all showing positive development trends for the future. Besides traditional sectors like transport, fishery, dredging and military activities, new applications are affecting Baltic space. Next to SUBMARINER uses like offshore energy installations (wind, waves) and mariculture, also oil and gas extraction, new types of maritime tourism or the release of cooling waters from power plants are among those human

Figure 12: Map showing spatial conflicts of several uses in the Baltic Sea. Data from HELCOM and WWF.



activities which put pressure on the Baltic Sea environment (figure 12).

The more uses compete for space, the scarcer and more valuable this space becomes. Thus the principle of spatial efficiency gains increasing importance. It postulates that uses should be concentrated as much as possible in one place/space on the basis of co-uses, synergies and multiple spatial use in order to maintain other areas free.

Both within the coastal zone as well as in marine areas problems are increasingly encountered in the allocation of space for each of the various uses. Classical examples of conflicts encountered are between traditional users (such as shipping, oil, gas or mineral extraction and fishing) and emerging activities (such as tourism/recreational uses, aquaculture and in particular, offshore renewable energy sector) as well as marine protection (incl. marine protected areas and marine and coastal Natura 2000 sites).

To improve the situation the concepts of Integrated Coastal Zone Management (ICZM) and Maritime Spatial Planning (MSP) have gained importance during the last decade.

- ICZM is more focused on land and the immediate shore vicinity and aims at a comprehensive management framework for the whole coastal zone. The ICZM recommendations adopted by the EU in 2002 outlined the principles for sound planning and management as well as the steps to be undertaken by Member States in order to develop national ICZM strategies.
- MSP is commonly defined as a tool to allocate the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives. It was identi-

fied as one of the cross-sectoral tools supporting the implementation of Europe's new Integrated Maritime Policy, but its implementation is seen as a responsibility of Member States.

Most important for both concepts is their forward looking direction, thus not only searching for conflict resolution between current uses, but also anticipating future developments and thus creating synergies while avoiding conflicts from the outset. Both tools seek to shape and guide future developments rather than passively react to them.

The Baltic Sea Region has been a driving force in the development of MSP. As early as 2001 it laid the foundation for this new policy instrument with the publication of the VASAB 2010+ Spatial Development Action Programme. Ever since, competence has been built throughout the Baltic Sea Region within numerous projects like BaltCoast, PlanCoast, BaltSeaPlan and Plan Bothnia. The creation of the joint HELCOM – VASAB Working Group for Maritime Spatial Planning in 2009 and the subsequent adoption of a set of joint principles for broad-scale transboundary MSP in the Baltic Sea by both organisations has been yet another milestone.

While MSP is far from an established practice, more an more Baltic Sea Region countries have started to introduce the relevant MSP legislation and appointed institutions responsible for MSP. In the case of Sweden this has even led to the creation of new organisations like the Swedish Water Management Agency.

The establishment of selection criteria for suitable sites, understanding the range of their (positive or negative) environmental impact, the promotion of efficient use of space, and combinations of multiple uses in the same areas (such as offshore wind parks and aquaculture) is an underlying theme throughout the SUBMARINER project.

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

The "Spatial Vision 2030 for the Baltic Sea Region"[25] elaborated in the framework of the BaltSeaPlan project determines among others key principles for allocating Baltic Sea space and highlights a healthy environment, a coherent pan-Baltic energy policy, sustainable fisheries and safe, clean and efficient maritime transport at the core of pan-Baltic topics. All of them are highly connected to SUBMARINER uses.

Guiding principle	**Goal**	**Means**
Sustainability:	To secure economic prosperity, social well-being and a healthy and resilient Baltic Sea ecosystem at the same time.	Protection of the ecosystem integrity by minimizing the impacts of sea uses on the wider Baltic and use space frugally by keeping back as much space as possible
Pan-Baltic thinking:	"Think Baltic, act regionally" The Baltic Sea as ONE planning space and ecosystem at all stages of the MSP process.	Decisions based on commonly agreed environmental, economic and social quality objectives and targets developed for the whole Baltic Sea and ensure that these are not compromised by short-term gains.

Guiding principle	Goal	Means
Spatial efficiency:	Baltic Sea space is a valuable public good, and the Baltic Sea is no repository for problematic land uses.	Uses are concentrated as much as possible to keep other areas free, and co-uses, synergies and multiple spatial use are promoted. Immovable sea uses and functions such as existing infrastructure or habitats have priority in the allocation and designation of sea space and are an automatic consideration for priority status
Connectivity thinking:	Focus on connections	The different elements of a system should be connected across space and time, such as shipping lanes and ports, or habitats and breeding areas, or the present situation and potential future change.

Source: BaltSeaPlan/Vison 2030.[25]

ADDITIONAL POINT

DIFFERING RIGHTS/OBLIGATIONS DEPENDING ON SEA ZONES

According to the United Nations Convention on the Law of the Sea of 1982/1994 (UNCLOS) the sea is split into different zones. For the Baltic Sea the following three zones are of importance:

a internal waters on the landward side of the baseline
b the territorial sea extending up to 12 sea miles seawards from the baseline
c the exclusive economic zone extending up to 200 sea miles.

TERRITORIAL SEA

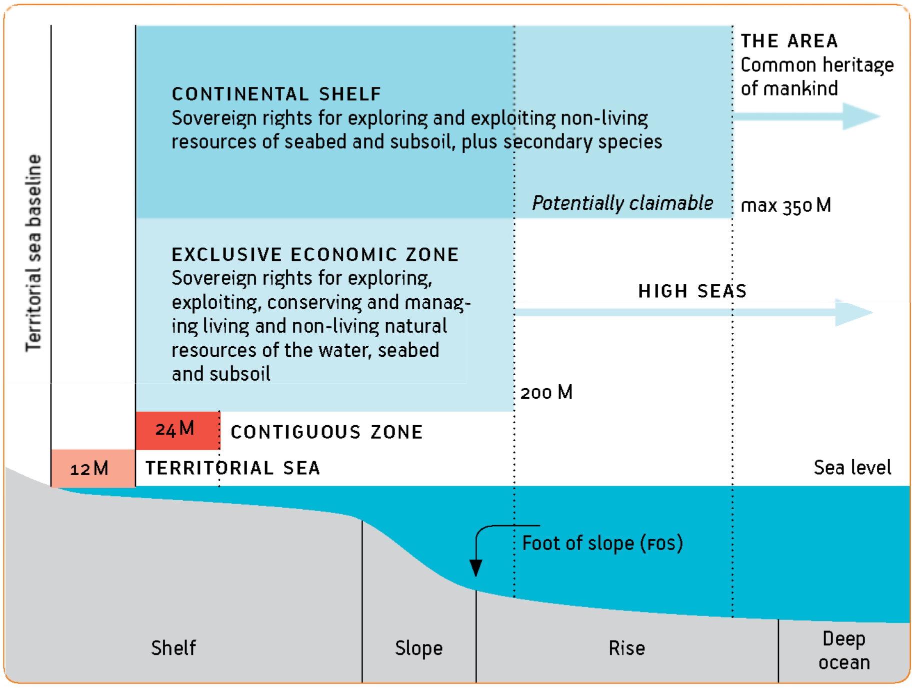
Within the internal waters and the territorial sea the Coastal States exercise full sovereignty, with the exception of the right of innocent passage of all other states in the territorial sea. Thus Coastal States are for instance allowed to grant permissions for installations and is accountable for nature protection regulations.

THE EXCLUSIVE ECONOMIC ZONE (EEZ)

Within the EEZ the Coastal State holds functionally restricted rights meaning that the State is not free in formulating laws, but is restricted to the extent of power assigned by UNCLOS. These provide for instance for :

- sovereign rights aiming at exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds;

- jurisdiction regarding to: (i) the establishment and use of artificial islands, installations and structures; (ii) marine scientific research (iii) the protection and preservation of the marine environment.



The term "artificial islands" means large constructions, derived from the deposition of building material as well as gravel, sand, stones or concrete, which are of artificial nature. Moreover, they permanently rise above the sea level and are not bound to a certain purpose. The term "installations" includes constructions, which permanently rise above the sea level as well and which are tied to the sea floor, for instance, oil rigs. They differ from artificial islands according to the circumstance that they can change their position while keeping their identity. The term "structures" comprises floating but anchored facilities and is supposed to cover those facilities necessary for marine aquaculture.

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Macroalgae Harvesting and Cultivation

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MACROALGAE ARE MACROSCOPIC, MULTICELLULAR PLANTS that live in aquatic environments, mostly in the benthos (sea bottom). Some macroalgae are perennial, with slower growth rates and delayed reproduction, while other opportunistic species are rapid growing and short lived. They can reproduce both sexually and asexually. Macroalgae are classified as brown, red and green according to the pigments used in photosynthesis, which are also responsible for the different colours of algae. Most species live in salt or brackish (semi-salty) water.
Macroalgae are of great ecological importance since they act as one of the primary producers in the marine food chain and assist in supplying oxygen to the sea. They provide 30 % of the primary production in the coastal zone. Marine organisms seek shelter in macroalgae communities and macroalgae are food for a variety of grazers, like fish and invertebrates.

A Marine Resource with many Applications

Introduction

There is a long tradition of using macroalgae for different purposes, such as as food, animal feed and soil fertiliser. Asian countries in particular have a tradition of using algae dating back to the fourth century in Japan and the sixth century in China.

The total global production of aquatic plants was 19.8 million tonnes in 2010. The majority (95 %) of this production came from aquaculture and had a value of approximately € 4.3 billion. The remainder of the macroalgae came from wild harvesting. In Europe, however, the macroalgae industry, with a production of merely 82,000 tonnes in 2010 is not of considerable magnitude. Only about 700 tonnes of that volume came from cultivation.[1] Within the Baltic Sea Region, commercial use or production of macroalgae is still almost unknown.

There are, however, many reasons for the Baltic Sea Region to consider and encourage the innovative utilisation of macroalgae as a marine resource. Macroalgae are considered one of the most promising alternative feedstocks for production of commodities (e.g. food, feed chemicals and biofuels) and several projects have been initiated in Sweden, Denmark, Scotland and Norway.[2-6] In addition, there are environmental benefits such as eutrophication mitigation tied to the removal of marine biomass and the use of macroalgae based energy lowers greenhouse gas emissions to the atmosphere. The harvesting of wild perennial macroalgae is not likely to be allowed but cultivation as well as removal of beach-cast and free-floating algae mats remain promising options.

While free-floating algae can be used for applications ranging from feed to bioenergy, its quality is rather low and certain end uses must be excluded. High-value macroalgae products used for human consumption, cosmetics and biotechnology (see “Blue Biotechnology” chapter) are in growing demand. For those products, good macroalgae quality is required and thus cultivation is necessary. Macroalgae cultivation also has the added benefit of serving to mitigate nutrient loading and to counteract eutrophication processes. Due to the fact that macroalgae cultivation remains a relatively unexplored field in the Baltic Sea Region when compared to other parts of the world, the information in this chapter focuses predominantly on the concept of harvesting wild macroalgae either in their free-floating form or as beach cast.

The Baltic Sea Region has the potential of producing renewable energy and other products from macroalgae biomass but progress remains slow. Without taking the necessary steps forward within the near future, there is a risk that the region will be left behind in the development of this resource use for its economic and environmental advantages.

Macroalgae in the Baltic Sea Region

Natural Factors

Macroalgae distribution is highly dependent on the physicochemical environment. Major environmental factors are light availability, temperature, salinity, bottom type, water motion and nutrient availability. Generally salinity is the most important abiotic factor controlling the distribution of species on a Baltic Sea-wide scale. It influences species diversity, reproduction cycles, growth rates and structure. Generally, the number of marine macroalgae in the Baltic Sea decreases from a few hundred species in the Kattegat to less than 100 in the almost fresh waters of Bothnia Bay.[7] In addition to salinity, light availability and temperature are also important limiting factors. Consequently, macroalgal populations are affected by seasonality and ice cover during winter.

Ecological Roles

Macroalgae can occur in three stages, all of which play important ecological roles in the Baltic marine environment: attached, free-floating and beach-cast. Attached macroalgae are primary producers for

Figure 1: Type of coastline, salinity and macroalgae species numbers in the Baltic Sea.[7]

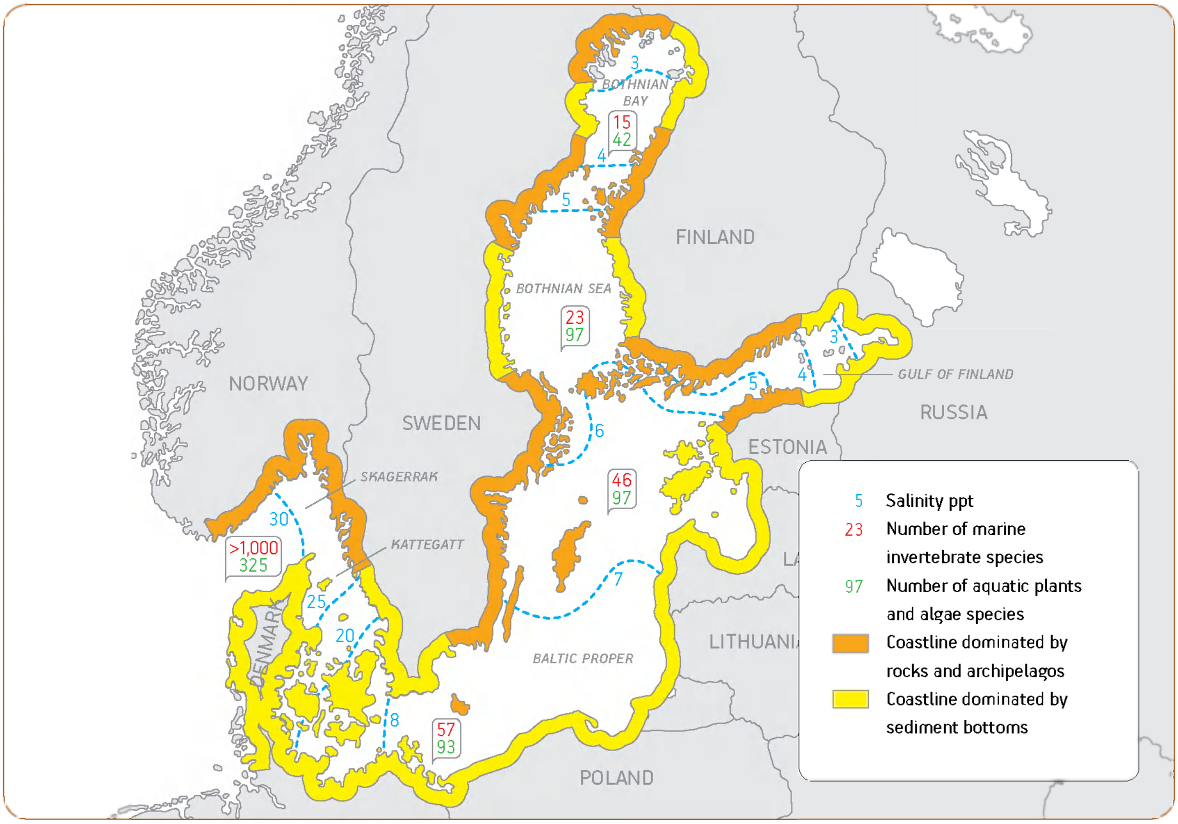


Figure 2: Ecological roles of macroalgae in the Baltic Sea.

Attached	**Free floating**	**Beach cast**
• Primary producer • Key species • Critical habitat important for recruitment of many other species • Food source and home for invertebrates • May be of structural importance	• Primary producer • Can still be growing and reproducing • Food source and home for invertebrates	• Important food source and shelter for invertebrates and shore birds • Nesting material for seabirds • Potential beach building material

key species, providing critical habitats essential for the successful recruitment of other species. They may also provide important structural barriers for coastal protection, buffering the impact of high-energy events on the shore. Free-floating macroalgae are also primary producers and can continue to

Figure 3: Main direct and indirect effects of eutrophication on macroalgae in the Baltic Sea, horizontal arrows represent the growth rate and vertical arrows represent positive or negative responses due to indirect effects.[8]

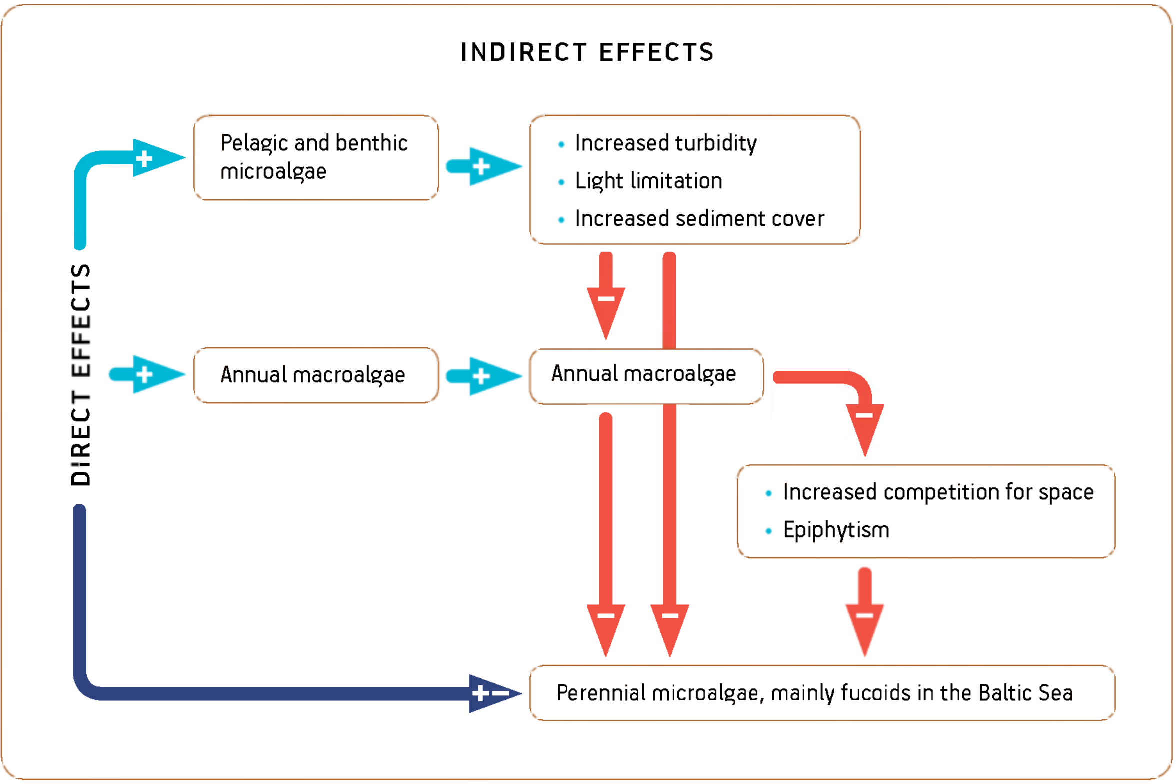
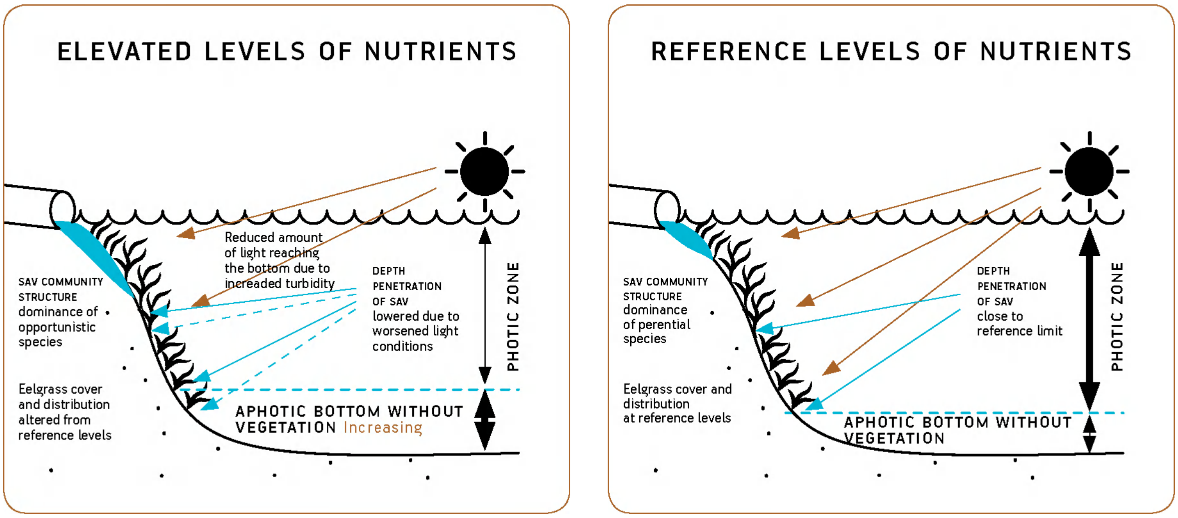


Figure 4: A conceptual model of factors affecting submerged aquatic vegetation in the Baltic Sea.



grow and may even have asexual reproduction while floating. Beach-cast macroalgae are an important food source and shelter for shore birds and provide nesting habitat for seabirds. Beach-cast algae also capture sediments and nutrients for dependent communities.

Anthropogenic Factors

Eutrophication of the Baltic Sea has both direct and indirect effects on macroalgal growth and distribution[8] (figure 3). High nutrient levels stimulate the growth of phytoplankton, which in turn limits the penetration of light needed for attached macroalgae.

Opportunistic and annual filamentous macroalgae are very good at using excess nutrients and they have a very high growth rate in optimal conditions. Fast-growing macroalgae usually win the competition for space and filamentous algae often overgrow perennial species, which further increases the shading and physical load. These filamentous algal species are found in all groups of algae: red, brown and green and are an increasing problem in the Baltic Sea given the high nutrient levels. They also form drifting algal mats in eutrophied shallow bays all over the Baltic Sea.

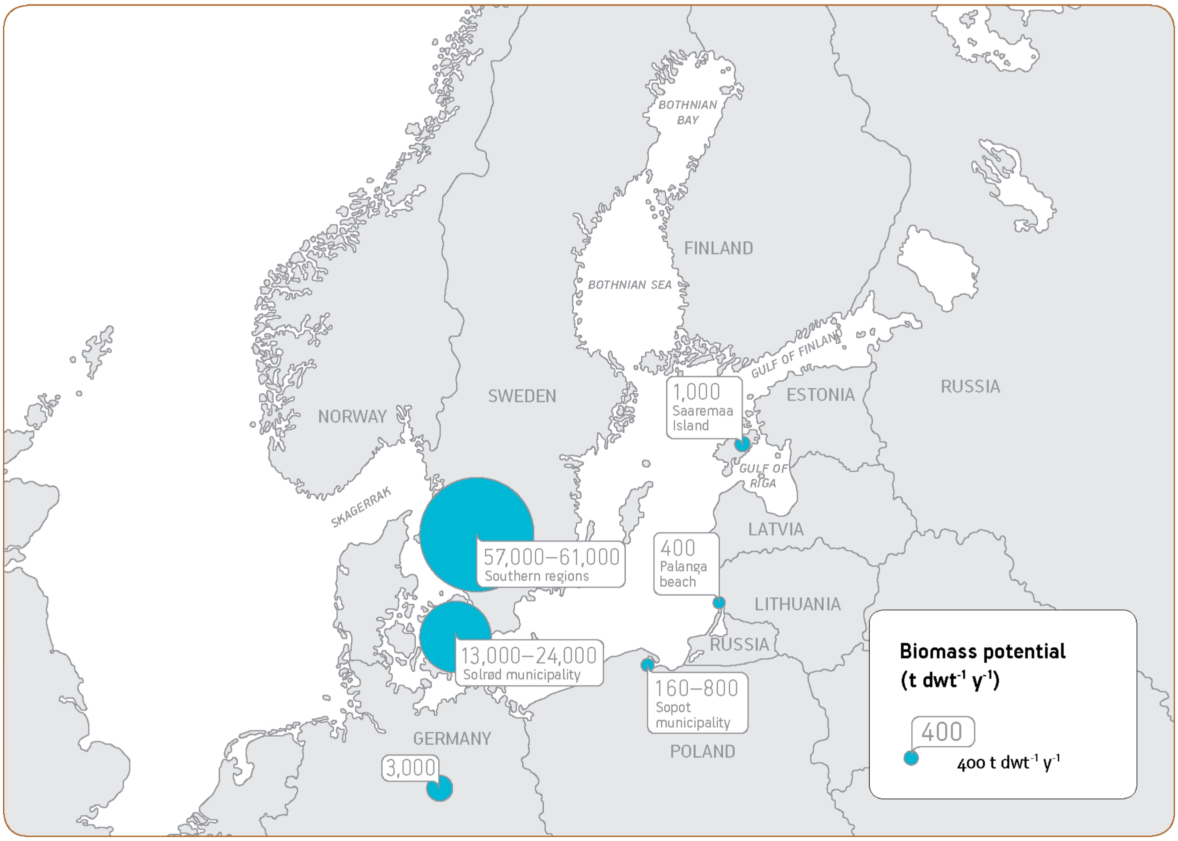
The depth distribution of macroalgae is mostly determined by light. With the increase of eutrophication, macroalgae communities tend to move towards the surface (figure 4).

Supply

As a result of eutrophication, an increase in filamentous macroalgae has taken place on the Baltic Sea bottom. During turbulence these algae come loose and continue living as free-floating mats as long as they are provided with sunlight and nutrients. Eventually they are washed ashore as beach cast. Beach cast assemblages are usually found on exposed beaches with predominant onshore winds, which are above all found in the southern part of the Baltic Sea including south Sweden and Denmark. The macroalgae in beach cast that are of interest to collect have to be as fresh as possible. Old embankments of organic material on the beaches will not be removed.

In view of seasonal variations and the lack of systematic monitoring, it is very difficult to provide a comprehensive estimate of resource availability throughout the Baltic Sea or how much would be accessible for collection. Figure 5 provides a rough overview of the areas in the Baltic Sea in which

Figure 5: Areas of the Baltic Sea Region in which beach-cast macroalgae can be found and where its biomass potential has been estimated (in tonnes of dry weight per year).



the potential biomass available for collection has been estimated.

Although the supply of naturally available macroalgae for collection is substantial, there are also reasons to think about cultivating this resource. Only high quality cultivated macroalgae can be used for human consumption, cosmetics and biotechnology. The main constraint to macroalgae cultivation in the Baltic Sea is the low growth rate of marine species in sub-optimal conditions. However, some areas in the Baltic Sea may be more suitable than others, depending on species and purpose of use. In general, higher salinity is favourable for species of marine origin and is necessary to ensure high growth rates in large perennial brown algae, which are popular for cultivation in other parts of the world. On the other hand, ephemeral filamentous macroalgae may be a solution for cultivation that can work even in brackish waters with lower salinities. Such species are generally more tolerant and show a high growth rate under the right circumstances (e.g. high nutrient levels, warm temperatures and good light conditions).

Fouling species, the other algae and animals species that accumulate on the surface of the cultivated macroalgae, can cause lower yields. It is even common in other types of aquaculture such as mussel farming for other marine organisms to use the aquaculture constructions as a habitat and outcompete the target species. This will probably happen with algae ropes as well if there is no way of preventing the other organisms from settling. Furthermore, diseases such as red rot and pinhole disease have been reported from macroalgae cultivations in other

REGIONAL CASE

So far only one German company , CRM Coastal Research & Management, is currently making commercial macroalgal cultivation in the Baltic Sea (Kiel Fjord). Since 2001 the company has been cultivating the large brown algae *Saccharina latissima* to make extracts from it for cosmetic products, food and medical research. An example is the project Algae Against Cancer (AAC) where the company is using extracts from *S. latissima* and other macroalgae in tests for anti-viral, anti-tumour and anti-bacterial activities, in cooperation with the Medical University. From 2008 to 2011, the CRM ran a project ALGASOLAR, where *S. latissima* was cultivated in order to get biomass for energy (gas). The technique was well developed but unfortunately the algae grew well for one year and badly for two years. After the laboratory phase, the 'field' phase is crucial. In some years diatoms competed with the macroalgae and overgrew them. The company has also developed a polyculture of the blue mussel *Mytilus edulis* and *S. latissima* on the farm in the Kiel fjord. This research is proceeding still.

parts of the world. Similar problems with infections may occur in the Baltic Sea but low salinity could lower the abundance.

Applications

Food

Macroalgae may be used for human consumption and is a healthy nutritional source: edible macroalgae have high water content, are low in calories and rich in vitamins and minerals. Some species are high in digestible proteins (20–25 % protein of wet weight) and the fibre content is usually higher than in terrestrial plants. In China especially, there is a tradition of using macroalgae directly as a food product. Brown and red algae species are mainly used but green algae may also be flavourful. The brown macroalga *Laminaria japonica* (know as kombu) is particularly popular. Moreover, the brown alga *Undaria* sp. (known as wakame) and the red alga *Phorphyra* sp. (known as nori) are economically important macroalgae species for human consumption. The interest in Asian food in Europe and the Baltic Sea Region has increased during the last decade but the use of macroalgae as food is still a small business.

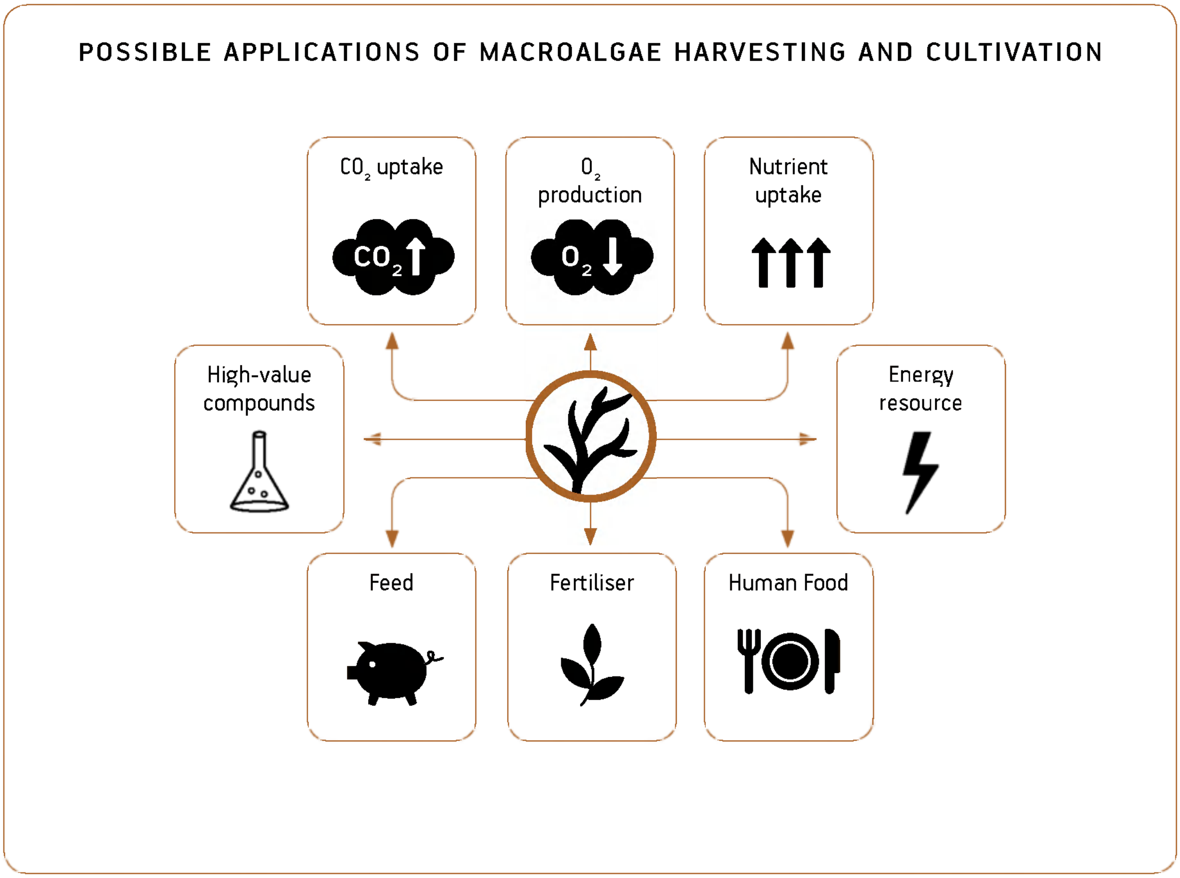
Feed

Macroalgae are also often used as an additives to animal feed due to their high content of minerals, trace elements and vitamins. Brown macroalgae are most frequently used for this purpose.

Gelling Substances

Another important and profitable global market is the extraction of substances from macroalgae, such as phycocolloids. These are natural products that serve to stabilise commonly used emulsions and dispersions in a large number of applications such as diary products, leather, textiles, cosmetics and pharmaceuticals. In 2009, a total of 86,000 tonnes of phycocolloids were sold, with an estimated value of approximately € 0.75 billion.[16] Brown macroalgae species of the genera *Ascophyllum, Durvillae, Eclonia, Laminaria, Microcystis,* and *Sargassum* are used for alginate extraction. *Gelidium* sp. and *Gracilaria* sp. are the two main red algae genera containing agar colloids.

Figure 6: Possible applications of macroalgae.



REGIONAL CASE

The Rebirth of New Algae Industries in the Baltic Sea Region?

The Latvian coastal region Kurzeme is rich in the red algae *Furcellaria lumbricalis*, which has been used since the mid-1960s as a raw material for the production of agar, a gelatinous substance used as laxative, vegetarian gelatine substitute, food thickener, clarifying agent in brewing as well as for sizing paper and fabrics. The production of agar was stopped in the 1990s after the collapse of the Soviet Union, but the potential for a restoration of the agar production industry in the area may be a realistic opportunity. Its is currently being assessed within the SUBMARINER project.

Also, in Kassari Bay in Estonia, loose-lying algae mats are being harvested for the extraction of hydrocolloids for food products, especially sweets. These algal communities consist primarily of *Furcellaria lumbricalis* and *Coccothylus truncates* and the algae have been harvested since the 1960s.

Biochemical Substances

In addition to the hydrocolloids described above, macroalgae also contain other useful substances such as antioxidants, pigments, enzymes and polyunsaturated fatty acids, which can be used in the biochemical industry for drugs, cosmetics and dietary supplements (see ”Blue Biotechnology” chapter). These substances may have a high value on the market.

Fertilisers

Macroalgae are used as fertilisers worldwide, as they not only contain nutrients such as nitrogen, phosphorus and potassium but also trace elements, vitamins and hormones that promote growth. Large brown algae are most commonly used but others can be used as well.

In the Baltic Sea there is a risk of high metal content in macroalgae due to a combination of high metal concentrations and low salinity in the waters. Macroalgae from the southern part of Sweden and Denmark generally have high contents of cadmium and thus macroalgae fertilisers will not be possible to dispose. There is no common EU-directive on cadmium content in biofertiliser and the regulations are different between the countries in the Baltic Sea Region. In Sweden, there is legislation about how much heavy metals that are allowed to be put on arable land. There are also certification systems with recommended limiting values for cadmium content in the biofertiliser. These are two factors preventing biofertilisers with high cadmium content to be attractive on the Swedish market. A cost-effective technique for cadmium purification is still not available although research is in progress. In other parts of the Baltic Sea where cadmium content is lower, such as in Poland, macroalgae digestate can be used directly without further treatment.

Bioenergy

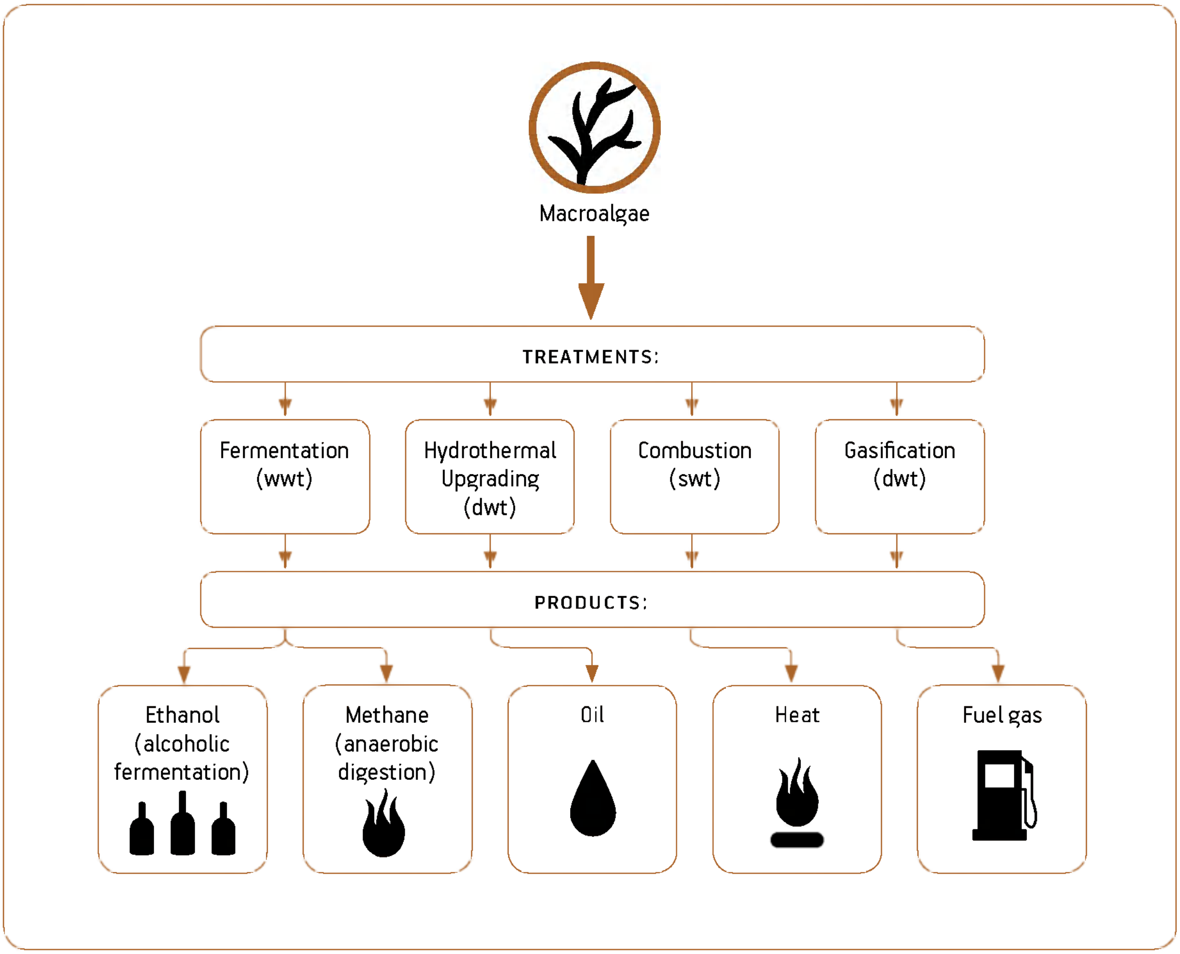
Shortages in biomass available for bioenergy production have increased the interest on the use of macroalgae. Macroalgae are typically high-moisture

Table 1: Examples of methane yield (normal cubic meter of methane gas per tonne volatile solids*) produced from crops or crop residues and different macroalgae species and the corresponding petrol equivalents (litre per tonne dry weight of biomass). Except from beach cast, the groups of macroalgae consider both “wild” and cultivated species.

Crop / Macroalgae Species	**Methane Yield (Nm_3 CH_4 t^{-1} VS)**	**Corresponding Petrol Equivalents ($l\ t^{-1}$ dwt)**
Crop or crop residues		
Timothy-clover forage, tops of sugar beet, maize[23-26]	270–370	270–380
Macroalgae species		
Red macroalgae beach cast[5]	130–200	120–170
Red macroalgae beach cast co-digested with reed (1:1)[5]	270	–
Brown macroalgae[26-30]	140–410	220–290
Red macroalgae[29-31]	190–400	130–290
Green macroalgae[3, 30]	160–270	100–170

*Volatile solids (VS) is the material content that burns off at 550°C i.e. organic matter content. High VS usually gives high biogas yield since it is only the organic part of the total solids (TS) that contributes to biogas production.

Figure 7: Technical options for producing bioenergy from macroalgae biomass.



material (80–90 %) and are considered to be more suitable for aqueous processing techniques such as anaerobic digestion or fermentation carried out by microorganisms.[22]

Anaerobic digestion uses anaerobic bacteria to breakdown or "digest" organic material in the absence of oxygen. Alcoholic fermentation processes carbohydrates into ethanol and CO_2. The production of bioethanol involves the fermentation of sugars by microorganisms. Both end products of these biological processes, biogas and bioethanol respectively, can be used for the generation of electricity and/or heat, or used as fuel in the transport sector. Biogas for use as fuel needs to be upgraded to methane.

Two of the main advantages of using macroalgae in biological processes compared with other material are the high water content, which can be mixed with dryer material, and the fact that macroalgal cell walls do not contain large quantities of hard materials such as lignin and cellulose that are difficult for microorganisms to break down. Some of the disadvantages of using macroalgae are the presence of salt, polyphenols in brown algae and sulphated polysaccharides, all of which can inhibit biological processes if not properly managed.

Many pilot projects on biogas production from macroalgae are currently being realised in the Baltic Sea Region, including some focusing on the biochemical processes of anaerobic digestion and

Table 2: Examples of ethanol yield (litre per tonne dry weight of biomass) produced from various crops and macroalgae species.

Species / Crop	Potential Ethanol Yield (l t^{-1} dwt biomass)
Crops	
Sugar cane[33]	70
Sugar beet[34]	110
Bagasse and other cellulose biomass[34]	280
Maize[34]	360
Macroalgae species	
*Saccharina japonica**[34]	140
*Kappaphycus alvarezii**[35]	150

*These species do not grow in the Baltic Sea

fermentation. Two of these examples, from the Trelleborg (Sweden) and Solrød (Denmark) municipalities are worth highlighting (see "Regional Case" frame on this page).

It has been suggested that until better yields can be obtained, ethanol production from macroalgae may not be a feasible business on a large scale.[32] However, this data shows that macroalgae fermentation has moderate potential for ethanol production, certainly one that is comparable to that of the most common substrates for bioethanol, sugar cane and sugar beet. Moreover, much research is going into solving technical problems with the alcoholic fermentation process and the development of a more efficient use of macroalgal substrate for bioethanol production can be expected in the future.

Nutrient Removal

Studies on the potential of Baltic macroalgae show that nitrogen content is around 2–6 % of the algae dry weight,[17-20] which is less than that of blue mussels.[19] The phosphorus content in macroalgae is usually less than ten times lower than the nitrogen content[20]. However, under certain local conditions in which substantial biomass is available, the effect of nutrient removal can still be quite substantial.

REGIONAL CASE

In the area of Trelleborg, Sweden, a case study was performed to assess the biomass potential for biogas production.[21] The harvesting potential was set to 10–30 % of the summer stock (growing attached and free-floating algae), which corresponds to 2,000–6,000 tonnes (dry weight) of biomass. This corresponds to a maximum nutrient reduction of approximately 50–150 tonnes of nitrogen, which is about 5–15 % of the freshwater run-off input of nitrogen to the Baltic Sea in this area.

In Denmark, the Solrød municipality is currently constructing a biogas plant fed by locally available organic resources.[15] One of the resources is cast seaweed collected from the beaches at Køge Bugt where 13,000–24,000 tonnes of dry weight are collected annually, which represents 120–210 tonnes of nitrogen removal per year. •

Competence Centres in the Baltic Sea Region

Below are a small selection of some universities, authorities and companies that make research on macroalgae use, work with or use macroalgae for different purpose in the Baltic Sea region. Research institutes working in the Submariner project are not included.

Sweden

Trelleborg municipality in Sweden take an active part in environmental projects for improvements of the water quality. The reason behind their specific interest in macroalgae is that Trelleborg has a long history of problems with beach cast. One of these projects is the The Cycle (Kretsloppet). Another project is the WAB (Wetlands, Algae and Biogas). The studies cover legislation on beach cast collection, marine monitoring, an environmental impact assessment of beach cast collection, and a control programme for a stream in the catchment area. Two studies on biogas production from macroalgae were also conducted. The project PhosCad, starting in 2012, will also be performed in the municipality of Trelleborg, since it has experience of macroalgae collection, biogas production and nutrient recycling. The aims are to optimise phosphorus extraction from macroalgae collected on the beach and develop techniques to remove cadmium from the algae. The **Swedish Environmental Research Institute** (IVL) will manage the project. The **Regional Council in Kalmar County** is running a three-year project (2009–2012) called "Biogas – new substrates from the sea". The main aim of the project is to find renewable energy sources so that the County can be free from the use of fossil fuels by 2030. To fulfil the goal, substrates for biogas other than household waste and manure have to be used and macroalgae, reed, blue mussels and fish wastes are being investigated for this purpose. There are several organisations and companies involved and **Linnaeus University** in Sweden are doing research in this project.

Halmstad and Laholm municipality on the south-west coast of Sweden have problems with beach cast and have received Swedish subsidies in 2010 to investigate cost-effective ways to remove macroalgae.

Estonia

Est-Agar AS in Estonia is currently the only company involved in the commercial use of wild macroalgae in the Baltic Sea Region. The perennial red algae *Furcellaria lumbricalis* is mainly used for the extraction of phycocolloids for food products. About 10 % of the product is used in Estonia, but most furcellaran goes to sweet factories in the Baltic States, Russia (Moscow and Petersburg) and Ukraine. **The Estonian Marine Institute** conducts annual studies to determine the level of algae that can be sustainably harvested in a given year.

Poland

The **Maritime Institute in Gdańsk**, Poland is going to apply for money for the research and development project: "Pilot study on macroalgae cultivation for the purposes of the environment protection and economy development".

The **Pomeranian Center for Environmental Research and Technology** (POMCERT) and the **Polish Institute of Oceanology** collaborate with the Swedish municipality of Trelleborg in the WAB project (see "Sweden").

Germany

Studies on the economic use of Baltic Sea red algae are being conducted by the **Christian-Albrechts University** in Kiel, Germany and investigations on production of the red algae by the **Institute of Biomedical Sciences, University of Rostock**, Germany. The studies are included in an existing project (2009–2012) about an artificial reef called Nienhagen, where macroalgae farming is a part of the work. It is named 'Trial of an aquaculture project to produce the red alga *Delesseria sanguinea* at the reef Nienhagen and further investigations on the economic exploitation of the sulphated polysaccharides of this alga".

The company **Coastal Research & Management (CRM)** conducts macroalgae cultivation and research in the Kiel fjord, Germany. Since 2001 the company is cultivating Saccharina latissima to make extracts from it for cosmetic products, food and medical research.

Denmark

CP Kelco ApS is a Danish company using macroalgae in the production of carrageen but it also produces pectin and refined locust bean gum. Raw materials are shipped in from all over the world for extraction, purification and standardisation in highly automated processes, and more than 95 % of the production is exported. Farmers around the country use the by-product from pectin production as a cattle feed supplement and the residue from carrageenan production is used as a fertiliser. The plant is located in the municipality of Solrød, Denmark. The **municipality in Solrød** is planning to start a biogas plant in 2013. The substrate will mainly consist of pectin production waste from CP Kelco ApS and beach cast.

AlgaeCenter Denmark conducts research on macroalgae cultivation. The land-based cultivation facilities are located at the Kattegatcentret at Grenaa Harbour. The consortium partners are the **Department of Bioscience at Aarhus University** (former NERI), the **Danish Technological Institute**, the **Kattegatcentret** and the **Ocean Centre Denmark**. Specific goals are to estimate the growth potential for sea lettuce in land-based basins, to design growth basins and harvest technologies for macroalgae cultivation, and to analyse the compounds in the algae biomass and assess whether sea lettuce is suitable for combustion, gasification and production of bioethanol and biogas.

A Danish company, **Blue Food A/S**, Hoyberg, has also been involved in a project about cultivation of *Saccharina latissima*. The project was mainly carried out in Trondheim, Norway, where the intention is to cultivate for biofuel production, but people in Grenaa in Denmark and at Sylt Island in Germany were also involved. One of the aims of the study was to investigate possibilities of inducing sorus, i.e. structures producing and containing spores for asexual reproduction, in a year-round manner at different locations for future use in kelp aquaculture.

The **University of Copenhagen** has been involved in macroalgae cultivation experiments in-Limfjorden, Denmark. The aim of the project was to evaluate production of *Laminaria digitata* and *Saccharina latissima* for energy production.

Technology

Harvesting Technologies

Harvesting of macroalgae was traditionally done by hand, which is certainly the most environmentally friendly way. There are also several different methods available for collecting macroalgae on the beach and in the adjacent water with the help of machines.

Advantages and disadvantages of the various methods are discussed in two reports by the South Baltic Programme funded "Wetland, Algae and Biogas" project[36, 37] with the following table summarising the findings.

In Trelleborg, Sweden, the grip-claw loader was considered as the best alternative for collecting beach cast, though another machine is needed to make the supplementary work of re-establishing normal beach conditions. For the removal of floating macroalgae in the water, an amphibian machine called *Truxor* is used, though its effectiveness is questionable.

Since biogas production requires fresh macroalgae for high biogas yields, there is a need for more cost-effective machines that could collect the biomass in the water. This is also important to get low amounts of sand in the substrate and to minimise the volume for transportation. Moreover, it is desirable to find a way to remove free-floating algae in

Table 3: Advantages and disadvantages of the various harvesting methods.

	The Grip Claw	**The Pinch Fork (DM Truxor 4700B)**	**Modified pea reaper**
Advantages	• Very efficient, can collect 45 m^3/hour, most effective for collecting large amounts of algae • Good quality material, small sand content • Low tech, easily available	• Amphibian machine, can be used in wetlands and harbors • Minimum sand content • Sparse fork, less impact	• Collects in shallow water and dewaters material • Specially designed to collect algae without sound
Disadvantages	• Does not clean the beach for recreational purposes (another machine is needed to do the fine cleaning afterwards)	• Slow • Noisy, disturbing if used in summer season	• Trailer fills up quickly, emptying process is time consuming • Not yet in production/ commercially available • Sensitive for stones on the beach.
			

the harbours, where the algae-layers sometimes are so thick that the pleasure boats have difficulties to enter the jetties.

In some areas of the Baltic Sea, constraints may exist on the use of motor vehicles on beaches or payment of a fee may be necessary, as is the case on the beaches on the coast of Latvia.

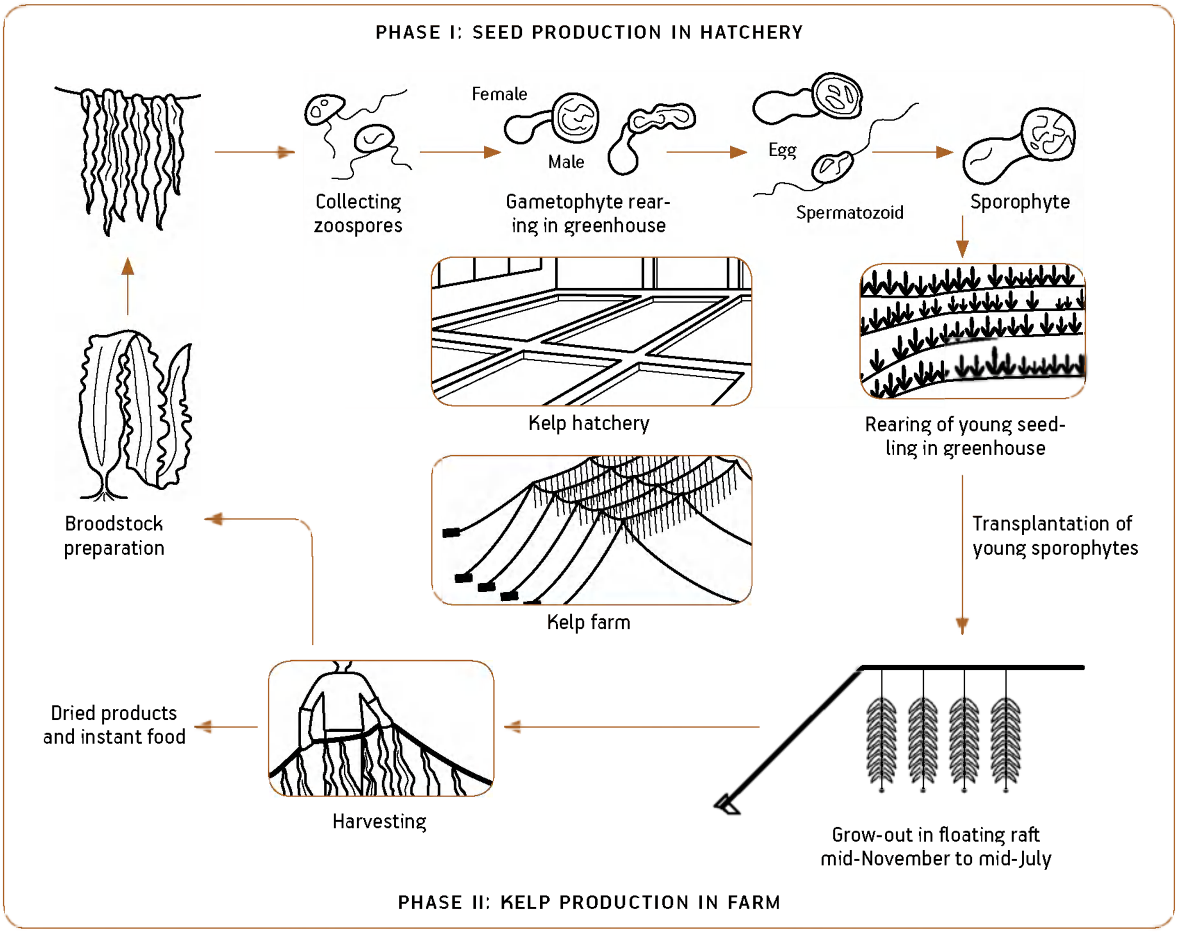
Cultivation Technologies

Many macroalgal species are easily cultivated and the equipment can be very low tech and simple or very advanced and expensive. The main cultivation steps are shown in the figure 8, starting with the collection of fertile specimens in wintertime and ending with harvest in late summer.

Long-line is the most common way to cultivate macroalgae due to its simplicity and low costs. Harvesting can be made from small boats either by cutting the algae from the rope or by bringing the ropes into the boat.

For macroalgae cultivation on a large scale (>1,000 ha), the cultivation system must be simple, low cost and low maintenance. It must allow for a high light capture and high productivity, must be resilient to climatic conditions, have durability and life expectancy while allowing for easy harvesting and replantation. Optimisation of such a system is still a great challenge and will still require a lot of research and development. Available cultivation techniques for offshore farming have been

Figure 8: Cultivation procedure for *Saccharina japonica*. Source: FAO.



developed during the last decade with increasingly durable constructions that can withstand storms and high waves.

In the Baltic Sea, the ice cover may be a problem for cultivation constructions, especially in coastal areas. Means for either hiding the construction below the ice or removing the constructions to land during wintertime are necessary if cultivation is to be commercialised in the Baltic Sea Region.

Environmental Assessment

Environmental impacts

Harvesting of attached perennial macroalgae is considered to be unsustainable, as attached macroalgae play an important ecological role in the formation of habitat and they have very low growth rates in the Baltic brackish water. On the other hand, removal of beach-cast and free-floating algal mats in specific Baltic Sea regions suffering from chronic macroalgae blooms as a result of excess nutrient loading may actually have positive impacts on the local environment as it is a form of recycling nutrients and combating eutrophication. Furthermore, there is an added

Table 4: Overview of macroalgae harvesting and cultivation impacts on environmental objectives and priorities.

Environmental Objective	**Environmental Priority**	**Beach Cast**	**Algal Mats**	**Cultivation**	**Comments**
Water quality	Bathing quality	🔵	🔵	🔹	
	Water transparency	🔵	🔵	🔹	
	Eutrophication	🔵	🔵	🔵	
	Biogeochemical cycles	? 🔹	? 🔹	🔵🔴 ?	Unfavourable for benthos
Habitat / Species protection	Food web dynamics	? 🔴	? 🔹🔸	🔵🔴 ?	Depends on density of biomass, Unfavourable for benthos
	Biodiversity	? 🔴	? 🔹🔸	🔵🔴 ?	
	Benthic habitats		? 🔹	🔴	Depends on density of biomass
	Bird habitats	? 🔴		🔵	Important during over-wintering & migration periods
	Fisheries		? 🔹🔸	🔵	Depends on density of biomass
	Marine mammals			🔸	
	Marine noise		🔸○	🔸	Depends on technology
Coastal protection	Coastal morphology	🔸	🔸	🔵	Depends on location
	Scenery	🔵			
Climate protection	CO_2 Emissions	🔹🔸	🔹🔸	🔹🔸	Biogas production/harvest effort

🔵	strongly supportive	○	neutral
🔹	moderately supportive	?	gaps in information;
🔴	strongly not supportive	blank	not applicable
🔸	moderately not supportive		

bonus associated with using the harvested biomass to produce biogas.

Important considerations when assessing the environmental impact of harvesting beach-cast and free-floating algal mats are the ecological roles they play within the ecosystem, their relationship with different aspects of the community and their role in coastal protection. For both beach-cast and free-floating algal mats, this can be quite complex as there are a number of environmental priorities that are impacted by these activities (table 4). Furthermore, the environmental effects are dependent on the density of the free-floating algae mats and could be either positive or negative depending on the thickness of the mat layers.

Overall, the environmental impacts can be either positive, as in the case of water quality and nutrient recycling or potentially negative as in the case of food webs and coastal morphology. There are still information gaps, in particular from an ecosystem perspective and further research is required to underpin any environmental management plan for the exploitation of the resource.

In the case of macroalgae farming, this mostly occurs close to land and knowledge about environmental effects of cultivation is available only for coastal areas. Therefore the factors referred to in table 4 concern only littoral waters. They also pertain to studies from other parts of the world, since macroalgae cultivations are almost absent in the Baltic Sea today. Furthermore, any area planned for macroalgal cultivation has its own environmental conditions and prerequisites and environmental assessments must therefore be site specific.

WATER QUALITY

Most of the effects of macroalgae harvesting and cultivation on water quality are positive ones: it removes nutrients, increasing water transparency, providing a means of countering local eutrophication. It also allows for the removal of heavy metals that accumulate in the macroalgae and limits the harmful emission of toxins from decaying red algae. Thick algae mats may prevent water circulation and other physical conditions due to the cover of the water surface. In that case, the removal of the algae mats improves the conditions for marine life.

On the other hand, in the case of macroalgae cultivation, low oxygen levels may be found in the cultivation area, which could potentially have negative effects on bottom dwelling species. Large-scale cultivations may also have a negative impact on currents and water circulation, causing an increase in surface water temperature in summer time.

HABITAT AND SPECIES PROTECTION

In terms of habitat and species protection, both positive and negative impacts can be expected. The removal of the densest macroalgal mats is mainly considered positive for benthic organisms and fish as well as for the general diversity of species. This is the consequence of improved water quality explained earlier in this chapter. However, macroalgal mats are inhabited by a specific fauna that would be destroyed by the harvesting. Removal of the beach-cast algae also impoverishes the beaches, as the decaying macroalgae supply subtidal and surf zone communities with nutrients and organic matter which helps maintain coastal biodiversity and functioning. Damage to bird habitats and disturbance during breeding and migration seasons could also be a result.

Biodiversity can be positively impacted by macroalgae cultivation, as the algae act as suitable habitat for epiphytes and other fauna and provides shelter for invertebrates and fish. By providing coastal protection, cultivation areas may lead to increased fish abundance. However, cultivations in coastal areas may compete with natural aquatic plant populations for nutrients and sunlight, while enlarged fish populations may increase the grazing impact on natural algae populations.

COASTAL PROTECTION

Removal of beach-cast and free-floating algae can lead to the weakening of natural coastal protection and increased exposure of the shoreline to erosion.

Macroalgae farms may modify water movement, absorb energy and provide protection to coastal areas.

CLIMATE PROTECTION

Harvested macroalgae can be used as a resource for biogas production, thus positively contributing to the reduction in greenhouse gas emission.

Site Selection

Every region has its own site-specific prerequisites for harvesting and every environmental assessment needs to take local conditions into consideration. It is important to be mindful of the interplay with the local food web and balance the removal of biomass with the needs of the ecosystem. Moreover, the timing of macroalgae removal should be adapted to the needs of migratory and overwintering bird communities. Attention should also be paid to ensuring the protection of coastal areas that are vulnerable to erosion.

In the case of macroalgae cultivation, careful site selection is extremely important is to be environmental sustainable. There should be no conflict with existing natural populations and there should be minimal impact to the bottom sea life. Careful spatial planning is necessary.

High nutrient levels and the sheltered conditions provided by coastal areas are the priority environmental factors for macroalgae farming. The coastal farming area should also be placed where other maritime activities will not be disturbed. A list of parameters to take into account when considering suitable locations for farming should include: level of exposure, water depth (2–50 m), salinity, fouling species, bottom type for anchoring and rights of disposition over sea areas.[32]

Socioeconomic Aspects

The costs associated with macroalgae harvesting and cultivation are counterbalanced by a number of positive economic effects (figure 9). However, even though it is possible to express many of them in monetary values, the ecosystem services do not always correspond to a direct positive cash flow for the institution in charge of the harvesting (and or cultivation). This may change depending on political will. For instance, some county administrative boards in Sweden have effectively distributed subsidies in cases where the aim of the macroalgae collection was to remove nutrients from the Baltic Sea.

In some cases, it is the municipalities who run the macroalgae harvesting initiatives, as is the case in Trelleborg, Sweden and Solrød, Denmark. The main reason is probably because the municipalities already had to pay for removal of the beach cast for recreational purposes. The municipalities can also best translate societal benefits into real income for the community (e.g. higher tax income due to higher tourism numbers / higher housing values).

Table 5 gives a rough overview of the costs and benefits derived from the collection of free-floating macroalgae and beach cast based on data from Trelleborg, Sweden. The Trelleborg municipality has

Figure 9: Simplified diagram of a socioeconomic valuation for macroalgae utilisation for biogas production (beach-cast and free-floating as well as cultivation). The diagram assumes that the collection of beach cast has no ecological consequences except for possible effects on commercial fish stocks

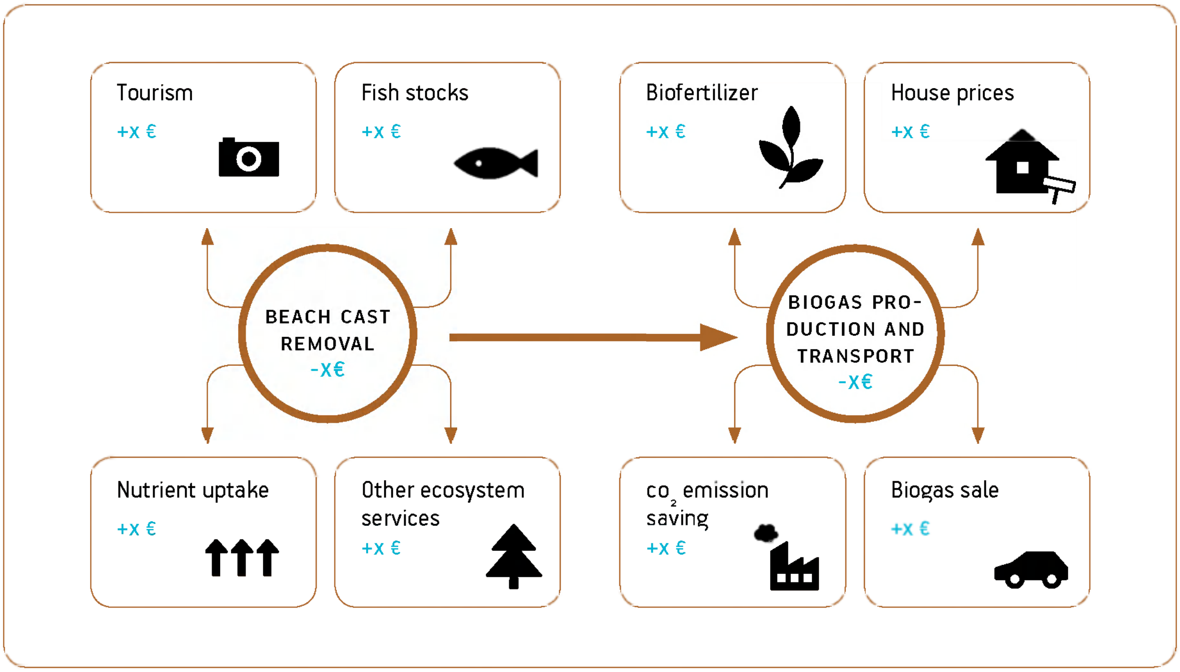


Table 5: Rough overview of costs and benefits derived from collection of free-floating macroalgae and beach cast (based on data from Trelleborg, Sweden).

	Costs (€ per tonne per year)	**Benefits (€ per tonne per year)**	**Comments**
Monetary costs and benefits			
Beach cast removal	140		Comparable with the cost of € 146 per tonne dry matter beach cast in a German study[14]
Biogas production / transport and sales	20–40 60–80	90–170 320	Raw biogas Upgraded bio-methane
Fertiliser	–	0	In the case of Trelleborg, the harvest is not always usable due to the presence of cadmium, though elsewhere it might have real economic value[40]
Total sum for monetary costs and benefits:	160–180 200–220	90–170 320	Raw biogas Upgraded bio-methane
Valuation of ecosystem services			
Tourism	–	750–1,070	In certain cases real values are available, e.g. beaches at camping sites[41, 42]
Fish stocks	–	–	Cannot be valued for the Trelleborg case but a loss of income of € 5.5-6.8 million per year has been suggested for another part of Sweden
Nutrient uptake Nitrogen Phosphorus	 – –	 580 980	Values suggested by a study[44] using the marginal cost method. Values would be lower when applying the willingness to pay method[45]
Other ecosystem services	–	–	Relates to biodiversity or resilience Not valuated here[46]
CO_2 emissions savings	–	1.5	Based on price of voluntary payment[47]
House prices	–	–	Cannot be valued at present but may reduce property values with 50%[48]
Total sum for ecosystem services:	0	2,310–2,630	
Total sum for all costs and benefits:	160–180 200–220	2,400–2,800 2,630–2,950	Raw biogas Upgraded bio-methane

great problems with macroalgal assemblages: the macroalgae cover large areas of the shallow water, create embankments on the beach that keep people from swimming and create a bad odour problem (figure 10). The table is based on a resource potential of about 6,000 tonne dry weight of macroalgae per year but shows costs and benefits per tonne dry weight for readability. In this case, it is assumed that the macroalgae were collected in an environmentally sustainable way, without any negative ecological effects. Basic economic data on biogas production obtained from Trelleborg municipality were used in the case study.[12, 38] Data on costs for collection of macroalgae are mainly from Detox Biogas AB.[39] Additional references are given as comments in the table.

If ecosystem services are not included in the system, the business of collecting 6,000 tonnes of beach-cast and free-floating macroalgae close to the shore is not always profitable. The production of raw biogas could result in a loss of approximately € 90 per tonne per year. With a lower cost of production and a higher sale price for raw biogas, the calculation is almost balanced, with a profit of approximately € 10 per tonne and year. For methane production, the profit varies between approximately € 100–120 per tonne and year.

When ecosystem services are included, the profit will be approximately € 2,220–2,640 per year for each tonne of macroalgae sold as raw biogas. For an upgraded product, vehicle fuels, the profit ranges between about € 2,410–2,750 per tonne and year. The two items that are not valued, fish stocks and house prices, can be assumed to be positively impacted and thus will increase the benefits. This shows the importance of understanding the environmental and societal benefits that accompany this type of activity and of including these values in economic calculations.

When it comes to cultivating macroalage, very few studies to date have examined the socioeconomic aspects and cost-benefit analyses focused on the Baltic Sea are not available. One study[32] refers to literature values on the costs of macroalgae farming in the Baltic Sea ranging between € 30–90 per tonne of dry weight, but benefits, particularly ecosystem services, are not included in that study. As with the harvesting of beach-cast and free-floating algae, it is possible that macroalgae cultivation for bioenergy production is not economically feasible if additional social and environmental benefits (such as ecosystem services) from the activity are not included in the calculations. These additional values could also include options like the extraction of high-value substances from the algae before it is used as bioenergy substrate.

Political Strategies

The Baltic Sea Action Plan and EU-strategies on the marine environment, integrated coastal zone management (ICZM), sustainable aquaculture and renewable energy etc. affect macroalgae use in the Baltic Sea region on a national level. Especially with regard to nutrient removal there are more and more suggestions to also take into account measures for remediation at “non-point source” and to investigate on appropriate payment schemes for making such nutrient removal measures worthwhile.

However, no national policies that specifically deal with the use of beach cast or macroalgae cul-

Figure 10: Algae beachcast in Trelleborg, Sweden (left) and Kurzeme, Latvia (right).

tivation are known. So far mainly regional or local documents e.g. on how to handle beach cast can occur. It can be noted that although macroalgae cultivation is a part of aquaculture activities, policies on sustainable aquaculture usually focus on fish and other marine fauna. The reason is probably that cultivation of macroalgae is almost absent in the Baltic Sea region at present.

Legal Aspects

Macroalgae Harvesting

Harvesting of attached perennial macroalgae is considered unsustainable and it is not likely to ever be allowed in the Baltic Sea due to the ecological importance of these algae habitat and their slow growth in brackish waters. On the other hand, harvesting of beach-cast macroalgae contributes to the implementation of the HELCOM Baltic Sea Action Plan as it removes nutrients and decreases eutrophication.

However, the network of protected sites subsumed under NATURA 2000, established by the EU Habitats Directive and Birds Directive, imposes restrictions to macroalgae removal. While harvesting of beach cast improves the quality of bathing areas, it may also deprive habitat types listed in Annex I of the Habitats Directive which call for protection. Those include, for instance, the habitat type "annuals on drift lines" (code: 1210, class: *Cakiletea maritimae*). Also *Rhodophyta* and *Corallinaceae* are among the species listed in Annex II of the Habitats Directive which require protection.

Thus an assessment according to Art. 6 para. 3 of Habitats Directive may be required since any plan or project likely to have a significant effect on a protected site shall be subject to appropriate assessment. This will be conducted by the competent authority of the Member State, which grants approval and has to be submitted by the applicant. Macroalgae harvesting may therefore be treated quite differently from region to region, depending on the respective local situation, making it difficult to provide a comprehensive overview on how the relevant legislation is applied in each case.

According to the Council Regulation on organic production, the collection of wild seaweeds and parts thereof, growing naturally in the sea, is viewed as an organic production method provided that the growing areas are of high ecological quality as defined by EU Water Framework Directive (2000/60/EC) and, pending its implementation, of a quality equivalent to designated waters under the EU Shellfish Directive (2006/113/EC), and are not unsuitable from a health point of view (Art. 13 para. 1).

In order to be "organic", wild edible seaweeds shall not be collected in areas which would not meet the criteria for Class A or Class B areas as defined in Annex II of Regulation (EC) No 854/2004 on products of animal origin intended for human consumption. Moreover, the collection shall not affect the long term stability of the natural habitat or the maintenance of the species in the collection area (Art. 13 lit. b)

Macroalgae Cultivation

The Council Regulation on organic production also contains provisions regarding macroalgae cultivation. The farming of seaweeds shall happen in coastal areas with environmental and health characteristics at least equivalent to those outlined for seaweed collection in order to represent an organic cultivation method (Art. 13 para. 2). In addition to this:

- sustainable practices are required all stages of production, from collection of juvenile seaweed to harvesting;
- maintenance of a wide gene-pool has to be provided, the collection of juvenile seaweed in the wild should happen on a regular basis to supplement indoor culture stock;
- fertilisers shall not be used except in indoor facilities and only after authorization for this purpose.

REGIONAL CASE

DIFFERENT RULES FOR DIFFERENT COUNTIES

Currently in Sweden beach cast is collected in four coastal counties in southern Sweden and Gotland on the basis of legal permissions.[49, 50] Harvesting aims at improving water quality and increasing touristic values of the area. In some cases, the macroalgae are used as fertiliser on local farmland or as substrate for biogas production in pilot projects.

- In Skåne County, special permits for macroalgae collection concerned exemptions to driving with machines on the beaches, exemptions from rules in natural reserves and from the protection of the right to use beaches. There is a demand to put some of the collected macroalgae back on the beach after the summer season. The reasons for this decision are that a lot of sand is removed, that the beach cast prevents erosion, and that the beach cast in itself is important for the flora and fauna. If the beach cast is considered as waste there is an additional problem, because then it has to be handled in a proper manner according to the waste legislation.
- Trelleborg municipality has a temporary permission to use 100 tonnes of macroalgae for biogas production.
- In Kalmar County (including Öland), beach cleaning in small scale is performed on several places. No permission has been issued since the County has judged it unnecessary according to the legislation in force).[2]

SWOT Analysis

GENERAL SWOT

STRENGTHS

- Attractive solution to combat eutrophication locally
- Several utilisation areas (e.g. energy, fertiliser, high-value products), particularly for cultivated algae, which is of higher quality
- Contributes to Baltic Sea Region political goals (e.g. production of renewable energy, combating eutrophication, decreased CO_2 emissions)

WEAKNESSES

- Potential high cadmium content in Baltic macroalgae limits its utilisation potential as fertiliser
- Essential gaps in the knowledge on the environmental impacts (e.g. links between ecosystems, effects on the food chain)
- Lack of experience/knowledge on commercial implementation, as few to no commercial operations are in place in the region
- Economic efficiency is hardly known at the moment
- Lack of Baltic traditions in the use of the macroalgae
- Socioeconomic benefits difficult to valuate

OPPORTUNITIES

- Growing demand for energy from alternative sources
- Growing prices for traditional energy carriers
- EU support in the form of energy and climate change policies, EU Blue Growth initiative under Integrated Maritime Policy and structural funds
- Growing developments in high-technology and the bioenergy production
- Global drive towards sustainable development
- Growing support for decentralised network economy

THREATS

- Worsening of Baltic hydro-meteorological conditions due to climate change
- Lack of financial support due to the actual economic and financial crisis
- Lack of political support at national level in the form e.g. of national energy policies ensuring stable level of energy prices from renewable sources
- Present legislation potentially hampering both macroalgae harvesting and cultivation
- Fluctuating market prices may have an impact on production of renewable energy

MACROALGAE HARVESTING

STRENGTHS	WEAKNESSES
• A common Baltic Sea Region, local, renewable and natural resources • Some experience is already available from a few pilot projects currently undertaken in the region • Contribution to the improvement of Baltic Sea ecosystem conditions • Several indirect socioeconomic benefits (higher recreational values, increased house prices, increased tourism, work opportunities, use of local resources)	• Information on resource potential hardly available • Unpredictable supply, as dependant on fluctuating environmental conditions • Limited beach cast utilisation potential due to its non-homogenous composition (i.e. cannot be used for some high-value products) • Insufficient technical solutions for the most environmentally friendly and cost-effective techniques
OPPORTUNITIES	**THREATS**
• Public support for beach cleaning already in place • Growing Baltic Sea Region tourism industry	• Potentially increasing nature protection requirements (NATURA 2000 habitats)

MACROALGAE CULTIVATION

STRENGTHS	WEAKNESSES
• Can improve local biodiversity and enhance coastal protection • For some species, cultivation may not require expensive technology • Combination with offshore wind farms potentially possible, thus avoiding future spatial conflicts • Does not compete with arable land for food production	• Technology development at low level in the region (propagation techniques, cultivation constructions, harvesting techniques) • Low growth rates of marine species in sub-optimal Baltic conditions • Potentially strong spatial conflicts with other uses in the coastal areas
OPPORTUNITIES	**THREATS**
• Growing demand for high-valued macroalgae products used for e.g. human consumption, cosmetics and biotechnology • Growing demand for Baltic Sea Region branded products • Development of offshore wind energy offering possibilities for combined installations	

Knowledge Gaps

There are already projects in the Baltic Sea Region that treat beach-cast and free-floating macroalgae as resources instead of "waste", with biogas production as the most common use. Nevertheless, there are still knowledge gaps that need to be fulfilled to determine if the activity should be promoted or not.

Macroalgae cultivation, on the other hand, is entirely in its initial phase in the Baltic Sea. Only with macroalgae farms will enough of the knowledge gaps be filled to make realistic scenarios whether macroalgae cultivation is possible in the near future.

Knowledge gaps for in both these fields of activity include:

- **The resource potential:** for beach-cast and free-floating algae collection, assessments of biomass, density and annual production rates of stocks of attached living macroalgae should be made to support the derivation of sustainable quantities of beach-cast and free-floating algal mats that can be harvested; for algae cultivation, suitable species and their growth in Baltic Sea cultivations should be analysed.
- **Technical development:** cost-effective collection techniques for beach-cast or free-floating algae, cultivation techniques targeted for Baltic Sea conditions, optimisation of biogas yields, purification of heavy metals in digestate, other potential marketable uses.
- **Environmental effects:** effects of both beach-cast and free-floating macroalgae harvesting as well as macroalgae cultivation on ecological interactions, food chain dynamics, community structures of fragile food webs and on the provision of ecosystem services; for macroalgae cultivation it is also important to better understand the biophysical thresholds for benthic communities beneath farm sites.
- **Socioeconomic studies** on costs and benefits of macroalgae harvesting and cultivation

Conclusions

Even if there are still knowledge gaps and space for technical improvements regarding the removal of beach-cast and free-floating macroalgae, there is also the potential for a sustainable use of the biomass for biogas production. If the collection is made with caution, the environmental advantages appear to outweigh the disadvantages. Many local governments that have problems with beach cast already spend money on beach cleaning and by using the "waste" in an innovative way, they can also contribute to a better environment and to improving coastal economies.

In the case of macroalgae cultivation, it is such a new and innovative business in the Baltic Sea Region, that knowledge and expertise are very limited. The biggest challenge will probably be to find suitable macroalgae species for cultivation in brackish waters, depending on what they will be used for. Functional cultivation techniques must then be developed for these specific species. But given all the environmental benefits it could potentially bring, there are strong indications that this could be a sustainable industry in the future. Holistic sustainability assessments are one way of integrating nature-society systems into a single evaluation. By conducting such assessment early in a process, the results can provide important information for decision-makers to judge if macroalgae cultivation projects should be promoted or not.

The largest obstacle to promoting macroalgae collection or implementing large-scale macroalgae cultivations may be to show the profitability for individual investors. From the rough economic overview it can be concluded that direct profits in monetary terms are relatively low, but this is also the case for other biomasses used for biogas production. Therefore the value in providing ecosystem services needs to be included in strategic analyses. To encourage private investors in such ventures, there will be a need to make a business case which includes the value in providing ecosystem services (e.g. nutrient trading schemes). There is also a room for energy companies to run such projects for environmental goodwill.

Recommendations

- Projects dealing with macroalgae utilisation should be encouraged and financed to a greater extent by governmental subsidies and research funds (high negative externalities require public intervention).
- More research is needed to investigate the resource potential and environmental impact.
- More research is needed for further development of technologies for macroalgae collection and cultivation as well as biofuels production.
- Initiatives towards legislation adjustment to encourage macroalgae collection and cultivation should be undertaken; both concepts should further promoted at a political level.
- Discussion on nutrient trading schemes, including remediation payment rules, should be undertaken in the Baltic Sea Region or the EU.
- There is a need for a network of local biogas plants in the region; a regional decentralised energy production network should be supported.
- Only native macroalgal species should be considered for cultivation.

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Mussel Cultivation

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MUSSELS ARE BIVALVE SHELLFISH (animals with two shells) and, like many other marine organisms, filtrating animals. They live by pumping in the surrounding water and filtrate off particles, mainly phytoplankton, and are considered keystone species in aquatic ecosystems. As the seawater is in continuous motion, new food particles are continuously brought to the mussels even if they are sessile. In the Baltic Sea, both the blue and zebra mussels can be found. The blue mussel is better adapted to the more saline waters of the Baltic (> 4 PSU) while the zebra mussel is found in fresher water environments (< 1 PSU) as can be found in most of the Baltic Sea inlets, such as the Szczecin, Vistula and Curonian Lagoons, the Gulf of Finland and the Gulf of Riga.

Mussels are characterised by annual reproduction. They produce larvae that remain within the plankton for several weeks and are concentrated by wind and water currents in embayments producing high settling numbers. Mortalities during the free-living larvae and metamorphosis stages are high.

Temperature and salinity are the most important environmental abiotic factors. The spawning period lasts from late spring to early autumn if the temperature is above 12° C.

A contribution towards counteracting eutrophication

Introduction

Globally (blue) mussel farming and harvesting is normally pursued in order to produce food for human consumption. The demand is steadily increasing but the main production areas in Europe have reached a level where they can no longer expand due to shortage of suitable farm areas. Thus there is occasionally even a shortage of mussels on the market.[1] Nevertheless seafood mussels cannot be expected to become a major product in the Baltic Sea, as the low salinity level slows down their growth and leads only to small sized mussels.

Mussel farming may, however, be an interesting option for the Baltic Sea Region as one of the few available operational, simple, flexible and cost-effective methods to counteract the negative effects of eutrophication caused by nutrient leakage from agricultural operations, sewage discharges and other human activities. Around 80% of the nutrients discharged into Baltic coastal waters come from diffuse emissions like run-off from forest – and farm land, atmospheric deposition and rural living and cannot be captured from point sources.

Mussels improve coastal water quality as they “harvest” nutrients through their food intake of suspended particles. Mussel farming can therefore be regarded as an open landscape feeding on land, but in the sea. The potential of mussel farming to improve coastal water quality in marine waters is scientifically well known.[2, 3, 4, 5, 6, 7] Numerous pilot studies have proven that the establishment of mussel farms has dramatic effects on water clarity, increasing light penetration and leading to a significant decline in chlorophyll-*a*.[8, 9, 10]

The mussel biomass, i.e. its meat, can be used as seafood (if coming from marine areas), high protein animal feed, as a fertiliser in agricultural operations or as an energy resource for biogas plants. Considering that the production of nitrogen as a fertiliser is an energy demanding and climate negative process and that phosphate is a limited resource on a global scale, the recycling of nutrients is strategic both from an environmental as well as a socioeconomic point of view.

Nevertheless, in the Baltic Sea, mussel farming for nutrient recycling has not gone beyond the pilot stage yet. The main obstacle so far is the lack of economic incentives, which are necessary since no "income" can be generated from nutrient harvesting. Of course, mussel farming should also not be viewed as the "magic bullet" solution against eutrophication as only a limited number of suitable farm sites exist in the Baltic Sea where mussel farming is actually possible. This is due to environmental or economic perspectives and/or because of other uses are already taking place at suitable sites.

Mussels in the Baltic Sea Region

Baltic Mussel Types

Along the Baltic coasts blue mussels (*Mytilus edulis)* and zebra mussels (*Dreissena polymorpha)* are identified as promising biofilters.[11]

BLUE MUSSELS

The blue mussel, *Mytilus edulis,* have smooth, equally "D" shaped, bluish-black shells that are linked together on one side by a hinge. The inside of the shell is pearly violet or white. The meat inside the shell can be a creamy colour, pink or orange. Projecting out from between the shells on one side is a bundle of tough, brown fibres called byssal threads, more commonly known as the beard. Mussels use these fibres to anchor themselves to stationary objects. A grown up blue mussel may reach a size of 7 to 10 cm.

Blue mussels are very common in the cold waters of the North Atlantic and Pacific oceans, which provide the ideal habitat. A scientific debate is ongoing whether the Baltic blue mussel community is made up by *M. edulis*, a related species *M. trossulus*, or a mixture of both. In the Baltic Sea, the brackish conditions and low salinity hamper the speed of growth and the size of this basically marine organism. It is only in the south western part of the Baltic where the blue mussel may reach a size of 4–6 cm. Compared to e.g. the Swedish West coast the growth in the eastern, central and northern Baltic is about one forth, since it takes roughly the double time for a mussel to reach half the size. On the other hand, the meat content is relatively higher due to the thinner shells of the Baltic mussels. In fact, the blue mussel is the most common organism in the Baltic and the whole population has the capacity to annually filter the total water volume of the Baltic Proper!

Figure 1: Juvenile blue mussels.

ZEBRA MUSSELS

The zebra mussel is also a filter-feeding attached bivalve forming dense colonies on various substrates in freshwater and slightly brackish habitats. According to paleontological and geological data, the zebra mussel *Dreissena polymorpha* (Pallas 1771) existed in the Baltic Sea drainage area during the interglacial time[12] but later became extinct and was re-introduced in the early 1800s.[13] Thus it is not an alien species *sensu strictu*, but rather a postglacial re-immigrant.

In the Baltic Sea, the zebra mussel has a relatively high abundance and distribution range in

Figure 2: Zebra mussels.

shallow coastal lagoons, estuaries, gulfs and inlets,[14] i.e. ecosystems mostly impacted by anthropogenic disturbance and land-based nutrient inputs (Figure 3). There, zebra mussels can be found from the upper littoral down to 3–4 m depth, on hard substrates (boulders, embankments, hydrotechnical constructions) and soft bottoms (sand, silt or mud).[15] An especially large biomass and abundance of zebra mussels can be found in the Curonian Lagoon (south-eastern Baltic Sea).

Existing Mussel Farms in the Baltic Sea

As can be seen in figure 3, only a limited number of mussel farm trials have been carried throughout the Baltic Sea.

BLUE MUSSEL TRIALS

The first known trial of farming blue mussels on ropes in the Baltic was carried out in the 1980s at the Askö Laboratory in Sweden. More recently, during the 2000s, a number of small-scale trials have been carried out in Germany (Kiel), Poland (Puck Bay), Denmark (Great Belt area) and Sweden (South and East coast and in the Åland archipelago). They showed that the basic concept of farming mussels on long-lines in the Baltic Sea works and that a net seemed to be the most practical and cost-effective substrate for mussel farming. As a result, three larger trials were launched in the late 2000s, one in Åland and two on the Swedish East coast.[16] These trials tested nets and pipes for flotation.

ZEBRA MUSSEL TRIALS

There are ongoing experiments with cultivation of zebra mussels in Germany/Poland (Oder Lagoon), in Lithuania (Curonian Lagoon) and in Sweden (Lake Mälaren). However there are still only very few data available on cultivated zebra mussel biomass production and filtration efficiency, so most of the information on these topics is derived only from blue mussel trials.

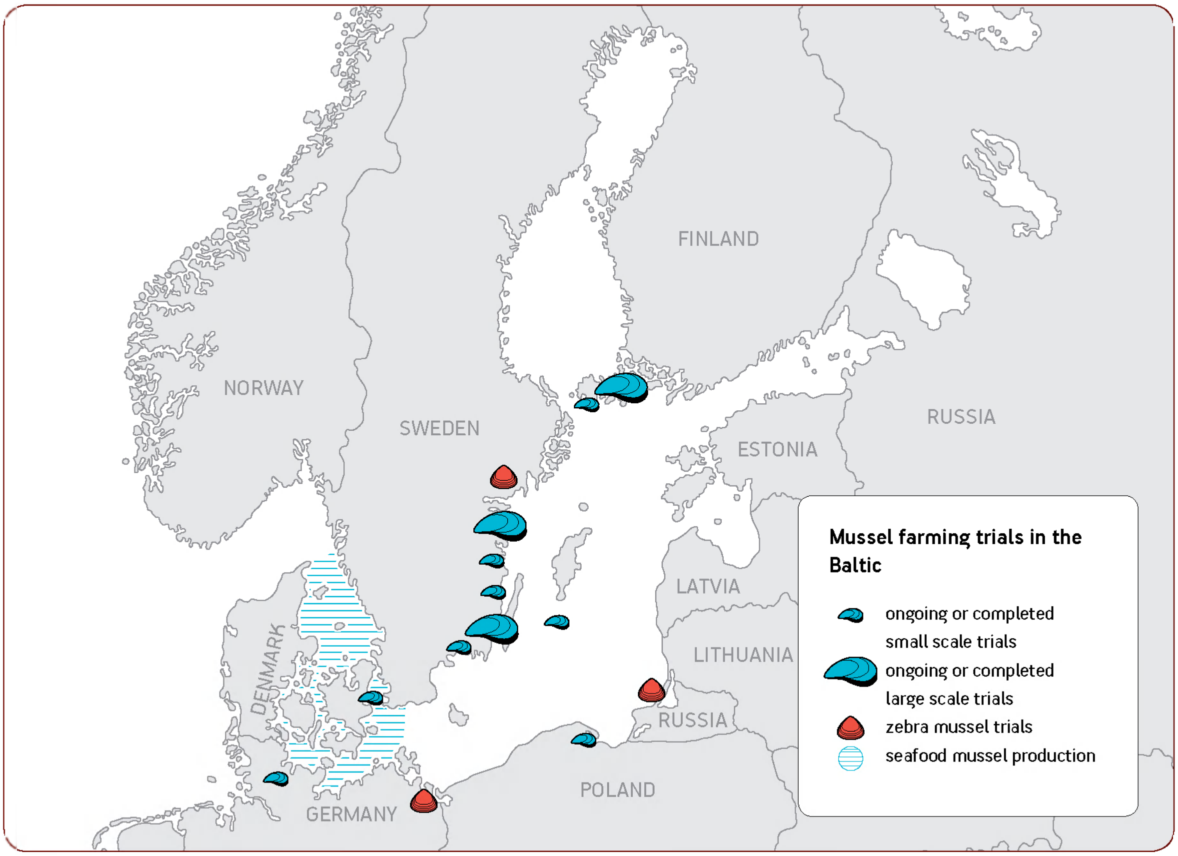
Growth and Biomass of Blue Mussels

In view of the limited amount of farm trials carried out in the Baltic Sea, there is still very limited data on growth and development of Baltic mussel biomass. However, the small-scale trials and experience from the marine areas of the Swedish West coast have provided some information about these parameters for blue mussels.

Many factors affect the growth of a mussel and there can be considerable variation within a limited area. The access of food is determined by the concentration of food in the area as well as the water circulation through the farm (e.g. with which speed food is brought to the mussels). A farming site with large water circulation and high phytoplankton concentration will result in faster growth of the mussels compared to a farm situated in an area with stationary water and containing small amounts of plankton.

Whereas one hectare of mussel farming on the marine Swedish West coast resulted in about 300 tonnes of mussels per hectare, harvested after 1.5 years of growth with about 25 hectares used for phytoplankton production for mussel food,[17] a similar calculation for the brackish Baltic Sea area estimated that maximum 150 tonnes of mussels per hectare could be harvested after 2–3 years of growth and an area of 7.5 hectares used for phytoplankton production. In short: Baltic mussels use

Figure 3: Locations of completed and on-going mussel farming trials in the Baltic Sea.



3 times less food supply area, require a long time to grow and are smaller in size (weight). This is mainly due to the lower salinity level throughout the Baltic Sea. Overall, that is large enough to make nutrient harvesting useful (100–150 tonnes of mussels per hectare) in 2–2.5 years at a good site in the Baltic.

Applications

Mussel use is mainly determined by its size and wet weight. Mussels catch and reuse nutrients and transform these into mussel meat, which in turn can be used as seafood, feed, fertiliser as well as a resource for biogas production.

Although worldwide there is currently no commercial or industrial use for the zebra mussel (*Dreissena polymorpha*) other than in trials for bio-filtration applications, it can be assumed that the same uses associated with blue mussels (with the exception of seafood) will also be possible for zebra mussels.

Lithuanian submariner Case Study

Due to its short and extremely exposed shoreline, the many competitive human activities and the influence of the diluted Curonian Lagoon plume, there are limited possibilities for blue mussel cultivation for remediation purposes along the Lithuanian coastal zone. However, there is an alternative: the zebra mussel *Dreissena polymorpha* in the transitional area of the Lagoon, between the Nemunas river mouth and the Klaipeda strait.

Zebra mussels are known to have been present in the Curonian Lagoon for at least 200 years and they are highly abundant in the central part, from the upper littoral to up to 3 m depths. Their distribution is restricted predominantly by brackish water inflows from the sea, hydrodynamic conditions and availability of suitable substrates for settlement.

The water quality of the highly eutrophied Curonian Lagoon (with a transparency range of 0.3–2.2 m and seasonal chlorophyll a fluctuations of up to 450 µg/l) cannot be sufficiently improved – enough to meet the EU Water Framework Directive requirements – through river basin management alone. Hence, zebra mussel cultivation in the Curonian Lagoon could be a promising additional remediation measure and could serve as a point-source filter reducing nutrient outflow to the Baltic Sea (which amounts to about 43,000 tonnes of nitrogen and 2,100 tonnes of phosphorous annually according to the recent calculations).

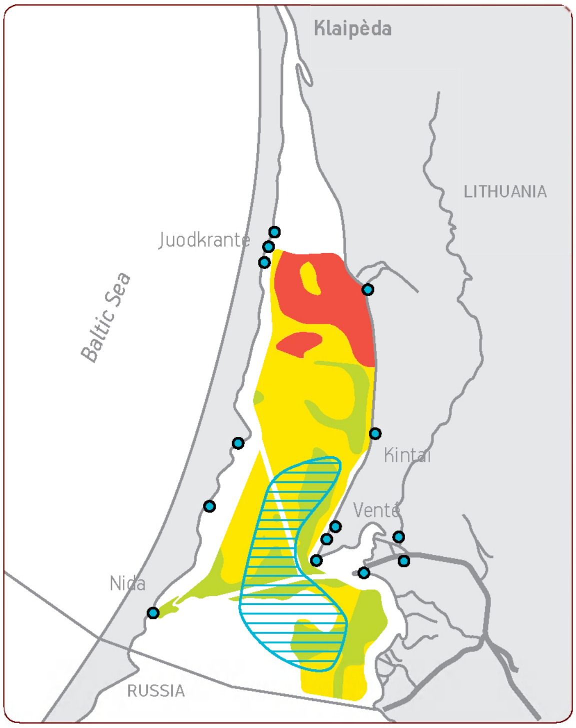


Figure 4: Potentially suitable areas for zebra mussel cultivation within the Curonian Lagoon.

Suitability conditions

- ☐ Unsuitable
- 🟥 Least suitable
- 🟨 Moderately suitable
- 🟩 Most suitable
- ▤ Distribution area of the zebra mussel population
- ● Berths

Based on the results of a case study conducted within the SUBMARINER project, the larvae of zebra mussels are available in the central part of the Curonian Lagoon from the late May to late July/early August in relatively high numbers (up to 500 individuals per litre). Therefore it is practical to install farming facilities during this period. Up to 4 kg of mussels per m2 could be harvested after one cultivation season (May–October). The concentration of toxic compounds in zebra mussels is well below the regulatory limits and much lower in young mussels compared to bigger ones. Based on these results and taking into account the specific environmental conditions of the lagoon (shallowness, hydrodynamic regime, pronounced seasonality, ice cover in winter and ice drift in spring), the seasonal zebra mussel farming is suggested as the most appropriate approach for the Curonian Lagoon. The potentially suitable areas for zebra mussel cultivation within the Lagoon are indicated in figure 4.

Zebra mussel farming could also provide a real economic benefit through the utilization of the harvested biomass in feed or fertiliser production. However, still a number of challenges to be overcome related to the lack of aquaculture tradition and experience in Lithuania and the absence of legislative regulatory mechanisms for such an activity. The approach described here for the Curonian Lagoon is also applicable to other Baltic Lagoons (e.g. Szczecin Lagoon), where zebra mussels are present.

Food Products

Most of the global mussel farming is intended to produce mussels for human consumption. The annual world production of mussels today exceeds 1.5 million tonnes, of which half is produced and consumed in Europe. Outside Europe, China, Korea, Taiwan, New Zealand, Chile and Canada are also important producers and exporters of seafood mussels.

Cultured mussels have a number of advantages over wild mussels. They do not touch the ocean bottom and are therefore free of the grit that often spoils the taste of wild mussels harvested from the ocean floor. Since they feed from the nutrient-rich water that surrounds them, they taste sweeter, are plumper, more tender, have thinner shells and yield a higher amount of meat than their wild counterparts.

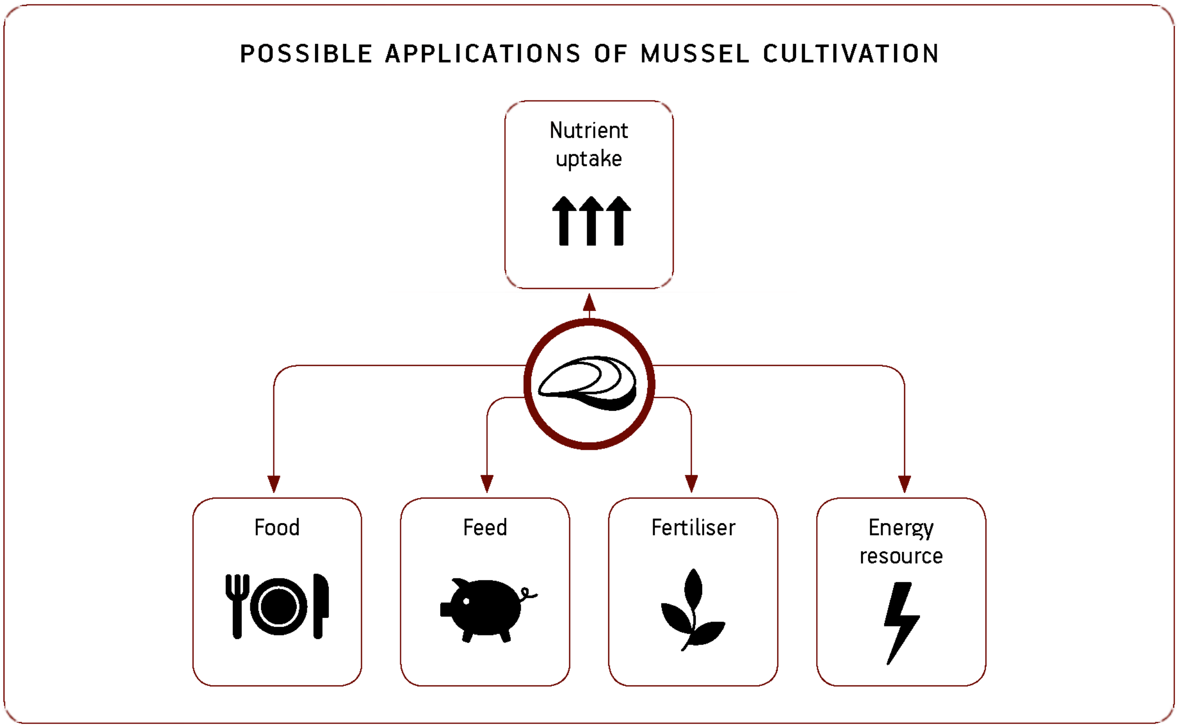
Both wild mussels as well as cultured mussels are available for seafood from the south-western part of the Baltic Sea (with a food mussel farm in operation in the Kiel Bay). With decreasing salinity levels towards the eastern parts of the Baltic Sea, blue mussels become too small to be used for traditional seafood purposes. Thus, this application will not become of major importance within the Baltic Sea Region.

Feedstuff

The blue mussel has a high content of the essential sulphur-rich amino acids methionine, cysteine and lysine, which match the content in fishmeal. They can, when shells are included in the feed, also provide calcium carbonate. At the same time, mussels are an excellent high protein feed for poultry as well as in fish feed and have a fat content of about 8 % (up to 40 % of which are Ω3 long-chain fatty acid molecules).

Measurements have shown that the meat content of Baltic blue mussels is around 22–26 %, which

Figure 5: Applications of mussel cultivation.



is higher than that of Swedish West coast mussels. This is another advantage of their use for feed production. In zebra mussels, meat content is about 16 % of dry weight on average. However, younger mussels (1 year age or less) show a higher percentage (up to 40 % of dry weight).

Since mussels are at the second step of the marine food chain, the use of mussels instead of fish for feed production also is of large ecological importance at a time when many fish stocks are overexploited on local, regional and global scales.

So far one sample of Baltic mussels (Hagby Harbour, Kalmarsund) has been analysed for use as feedstuff. This single result showed that the non-separated meat/shell meal mixture could, without further processing, be used as a high protein feedstuff and calcium source for egg-laying hens. Other feed options currently being tested are the use of mussel meal from fished mussels from the south-eastern part of the Baltic to be used in the aquaculture and breeding experiments of rainbow trout and arctic char, carried out at Rymättylä Aquaculture Station in southern Finland and at Kälarne Research Station in northern Sweden respecteively.[18] In Lithuania, the cast of zebra mussels and their shell deposits are already informally gathered from the shore and used as chicken feed additives by local farmers.

Fertiliser

The nitrogen, phosphorus and potassium levels in mussel biomass make it suitable for use as a fertiliser for grain cultivation.[6] The easily decomposed shells have a liming effect, i.e. they increase pH in acid soil, and a number of micro-nutrients such as selenium, copper and zinc are added to the soil. Discarded mussels used as fertiliser on farmland have given good results and are of special interest for organic farmers who cannot use commercial fertilisers. Studies have shown crop increases from 25 to 50 % compared to land that was not fertilised.[19]

ADDITIONAL POINT

Contaminants in Baltic mussels for use as feedstuff and fertiliser

An analysis carried out with blue mussels farmed from the Kalmarsund area (Sweden)[1] showed that concentrations of possible organic contaminants in the soft tissues and shells were safely below the regulatory limits applicable in Sweden for the use in feed or fertiliser.

According to the Lithuanian EPA monitoring data, in zebra mussel tissue samples from the Curonian Lagoon the concentration of the toxic compounds such as DDT, HCH and heavy metals was also significantly below the maximum allowable concentration.

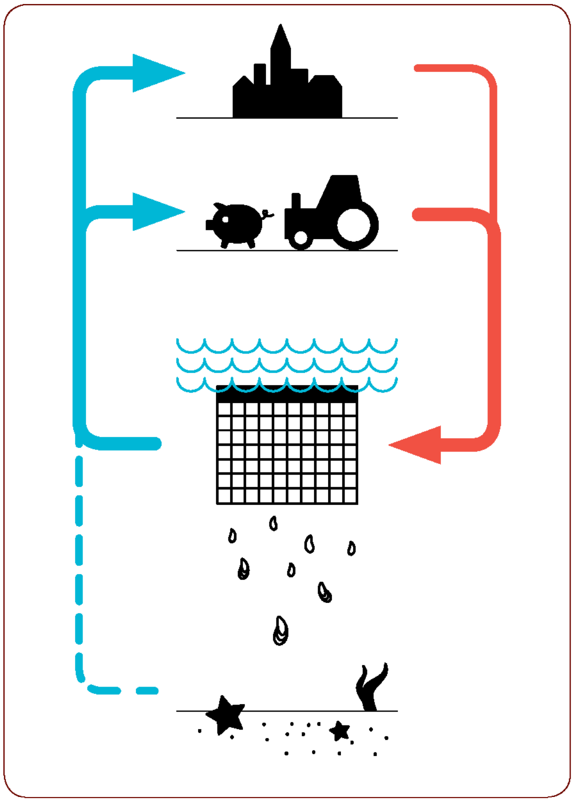
Table 1: Selected elements and substances in farmed and wild blue mussels from the Kalmarsund area on the Swedish Baltic coast, in relation to regulatory limits. Data from Nilsson, 2009[20].

	Farmed	**Wild**	**Feed Limit**	**Fertilizer Limit**
	(mg/kg dry weight)			
Elements				
Arsenic (As)	4.05	7.17	17.05	–
Cadmium (Cd)	0.85	2.53	2.27	2
Cupper(Cu)	7.72	11.60	–	600
Mercury (Hg)	0.05	0.11	0.57	2.5
Lead (Pb)	0.79	1.97	11.36	100
Polychlorinated biphenyls				
Sum PCB(7)	0.0142	0.0066	0.227	0.4
Chlorinated pesticides				
Hexachlorobenzene	<0.001	–	0.011	–
o,p-DDT	<0.001	–	0.057 (DDT)	
Dioxins and furans				
sum WHO-PCB-TEQ	1.12*10–6	–	5.11*10–6	–
Brominated flame retardants				
4-nonylphenol	<0.010	–	–	50
Toxaphene (sum Parlar 26,50,62)	0.000075	–	0.023	–

The mussel biomass had more or less the same effect as the same amount of manure fertiliser. Since the mussels live in saline water and ions of both sodium and chloride have a negative effect on some crops like potatoes, it is important that the water inside the mussels is drained before the remainder is spread on the farmland.

Other obstacles to the increased use of mussels as fertiliser are the bad smell generated during the deterioration of the mussel biomass as well as the fact that agricultural farmers only need the mussel fertiliser during certain periods of the year. However, composting experiments with straw or bark have shown that it is possible to produce a mussel fertiliser that can be stored and that shortens the period of bad odour. The bark compost also has a nice look with its dark bark and shiny shell pieces. Therefore it is anticipated that gardens and greenhouses could be a future market for such compost products.

Figure 6: The concept of "Agro-aqua recycling" was introduced by Haamer et al.[3]



Biogas Production

A study[21] has shown that anaerobic biodegradation is a feasible technique for the solubilisation and methanogenesis of blue mussels and that seeded batch reactors of low salinity (<10 g/l) can be employed to solve the problem of treatment and disposal of mussel wastes.

However, a sustainability evaluation of ecological engineering methods to recover biomass nutrient resources from the Baltic Sea[22] came to the conclusion that Baltic mussels are currently not suitable for biogas production due to a too high energy demand for harvesting, transportation and biogas production, which would result in a too low net energy balance.

Mussels as biofilters – nutrient harvesting

Probably the most important function of mussel farming in the Baltic Sea has to be seen in its ability to improve coastal water quality in marine waters. The idea of farming blue mussels in order to actively reduce the amount of phytoplankton and thereby the negative effects of eutrophication was introduced by Haamer.[23] In his concept, the increasing nutrient and plankton amounts in coastal waters are seen as a resource, which should be recycled to land and reused. In this concept, the farmed mussels should be brought to land in order to maximise the positive effect on the environment, i.e. the amount of harvested and recycled nutrients.

BLUE MUSSELS

Based on the small-scale trials and the experience from marine areas of the Swedish West coast, it is estimated that a nutrient harvest in the ranges given in table 2 should be possible from a given blue mussel farm site.[6]

Table 2: Nutrient harvest potential estimates for farmed blue mussels in the Baltic Sea.[16]

Coastal area	Biomass per longline or pipe (kg/m)	Estimated harvest per ha of farm (tonnes/ha)	Mussel meat content %	Estimated amount N (tonnes/ha)	Estimated amount P (tonnes/ha)
Southern Baltic	35	150	30	1.8	0.12
Northern Baltic	25	100	30	1.2	0.08

PUTTING IT INTO PERSPECTIVE

The Swedish share of the Baltic Sea Action Plan corresponds to an annual reduction of nitrogen of 21,000 tonnes and phosphorous by 290 tonnes, which means that about 14,000 ha of mussel farms should be harvested each year if the whole share should be carried out by mussels. This is of course far from realistic. A rough estimate is that mussels may be able to remove 2–3 % of the Swedish share, which is still substantial in relation to other treatment options. Note that both nitrogen and phosphorous are recycled in parallel by the mussels.

ZEBRA MUSSELS

Although the establishment of zebra mussels and subsequent retention of nutrients has likely counteracted the effects of eutrophication in many inland waters, few studies have quantified this. One study[24] recently showed that zebra mussels can greatly reduce algal biomass and negate or mask the increasing effects of nutrient pulses of phosphorus up to 150 mg/l on algal biomass. Several studies have therefore addressed the potential use of zebra mussels in water quality remediation or sewage sludge treatment and some pilots have also been carried out in the Baltic region. However there are still very few data available on the cultivated zebra mussel biomass production and filtration efficiency.

Competence Centres in the Baltic Sea Region

Table 3: Institutions involved in research and development of blue and zebra mussel farming within the Baltic Sea Region.

Institution or corresponding	Country	Mussel related activity	Web address
Askö Laboratory	Sweden	Marine research and education	www.smf.su.se/asko-laboratory
County Board of Östergötland	Sweden	Pilot project on growth of mussels	www.lansstyrelsen.se/ostergotland
East Sweden Energy Agency	Sweden	Project Baltic Eco Mussels	www.energiost.se
County Board of Kalmar	Sweden	Mussel farming for improving water quality	www.lansstyrelsen.se/kalmar
Göteborg Univ,.Dep. of Biol. and Env., Sciences	Sweden	Research and education on mussel farming as an environmental measure	www.bioenv.gu.se
Swedish Rural Economy and Agricultural Soc.	Sweden	Development of mussel meal production	www.hush.se
Novia Univ. of Applied Sciences	Finland	Project Baltic Eco Mussels	www.novia.fi
Husö Biological Station	Finland	Research and education	www.abo.fi/huso
The Åland Government	Åland	Development of mussel farming under Baltic conditions	www.ls.aland.fi
Klaipeda University	Lithuania	Research and development of zebra mussel farming	www.corpi.ku.lt
University of Gdansk	Poland	Development of mussel farming under Baltic conditions	www.ocean.ug.edu.pl
Sea Fisheries Inst. in Gdynia	Poland	Development of mussel farming under Baltic conditions	www.mir.gdynia.pl
University of Szczecin	Poland	Research and development of farming zebra mussels	www.us.szc.pl
Ernst Moritz Arndt University of Greifswald	Germany	Research and development of farming zebra mussels	www.uni-greifswald.de
Leibniz Institute for Baltic Sea Research (IOW)	Germany	Mussel farming research, development and education	www.io-warnemuende.de
Institut für Meereskunde in Kiel	Germany	Mussel farming research, development and education	www.ifm-geomar.de
Coastal Research & Managemant	Germany	Mussel farming research and development	www.crm-online.de
Aarhus University, Dep. of Marine Ecology	Denmark	Research and development of mussel farming as an environmental measure	www.au.dk
Danish Shellfish Centre	Denmark	Research and development of mussel farming as an environmental measure	www.skaldyrcenter.dk

Technology

The Basic Principle

The basic principle of mussel farming is very simple: male and female mussels spawn when the water temperature in spring reaches 10–12 °C and enormous amounts of eggs are released and fertilised resulting in pelagic larvae (open water drifting) called veliger. After roughly a month, normally at around midsummer, the larvae have reached a size of about 0.3–0.4 mm and will settle on a substrate and continue their life in a sedentary mode. In the sea there is most often competition for spaces to settle on and most hard surfaces are covered with algae, barnacles, mussels and other marine organisms.

The mussel farmer offers the mussel larvae a suitable substrate to settle on in the form of a rope, band or net. At a good site many thousands of larvae may settle per meter of rope or band. When growing, the numbers of mussels will be reduced and drop off due to limitations on the available space on the rope or band. At a marine site the number of mussels (40–70 mm in size) can, after 15–18 months at harvest, be about 500 per meter while in the Baltic the number of individuals (15–30 mm in size) after 18–30 months is about is 1,000–1,200.[25]

Cultivation Technologies

Within the last years, several projects have been carried out in the Baltic Sea to analyse and test different mussel cultivation technologies. Small-scale trials have included ropes, curled ropes, bands, net stockings and nets to be tested for settling of the mussel larvae and the following growth of the mussels. Results have shown that the basic concept of farming mussels on long-lines in the Baltic works and also that a net seemed to be the most practical and cost-effective substrate for farming.[25]

Mussel clumps that have settled on nets or lines over several years may break off and live on the sea bottom thus creating additional hard substrate for more mussels to settle. Although the use of submerged horizontal fishing nets has shown quite efficient settlement during field experimental studies, commercial cultivation mussels on horizontal net structures seem to be difficult to maintain and harvest.[26]

Therefore, other methods of cultivating mussels such as vertical line systems and single long tubes carrying vertical net collectors (“Smartfarm”) should be considered. Both systems are used all over the world including the Baltic (e.g. Kiel Fjord) for culturing seed and mussels.

Vertical mussel farm systems utilise the water body efficiently, maintaining high filtering areas and they are technically more adapted for commercial cultivation. This method is also more suitable

ADDITIONAL POINT

Is mussel farming really “farming”?

It could be pointed out that “farming” a mussel is an incorrect expression since you do not have to add any seeds, larvae or spat. Further, you do not add any fertiliser or feed. The blue mussel and its food intake are based on entirely natural resources regardless of whether it is wild or “farmed”. The bands, ropes, nets or other substrate which is offered to the mussels to settle and grown on can be compared with the concept of ranging wild deer by fencing an area for example. Thus, it is therefore suggested that “mussel farming” instead should be called “mussel ranging”.

for husbandry and harvesting using specialized machines. Permanently moored units can reduce labour costs significantly.

In Sweden, long-line farming is the most common method for mussel production. The mussels are mostly grown on vertical suspenders attached to horizontal long-lines (figure 7).

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

Based on the results of three large tests on Åland and on the Swedish East coast[16], it can be recommended to use a mesh size of around 150 mm and a net rope thickness of 10–12 mm. PVC pipes for flotation work well but require special equipment for handling and maintenance. For large scale farming, it is strongly recommended to buy equipment from experienced companies instead of using homemade solutions. However, the existing experience is too limited to be able to provide general one-size-fits-all solutions. It might well be that different parts of the Baltic require different technologies.

Figure 7: Schematic principle of a mussel farm unit using a net for settling of the mussel larvae and growth of the mussels and a pipe for flotation.

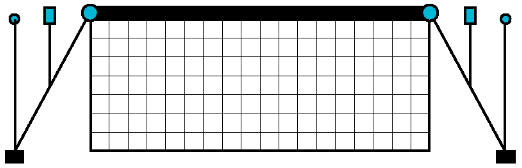


Figure 8: Mussel farming on a net.

Ice and Ice Drift

The large mussel farming trial in Kalmarsund, Sweden was extensively affected by the heavy drift ice in the winters of 2009–2010 and 2010–2011, with a lot of damage after the first winter and a complete break down during the second winter, although measures had been taken after the first winter in order to improve ice performance.

The experiences learned were used for designing moorings and buoys for another mussel farm trial at Kumlinge in the eastern part of the Åland archipelago. This farm survived well during the hard ice winter of 2010–2011 and is still functioning in 2012, which demonstrates that technical improvements are an important part of successful mussel farming in the Baltic.

Concerning ice and mussel farming in the Baltic, it can be concluded that during winter the lowering of farm units below the surface or a complete subsurface farming is a necessary future development. The farm methodology otherwise used so far was not good enough to survive the harsh ice conditions that may occur in the Baltic now and then.

An interesting observation made during the termination of the large scale farm trial in Hållsviken, south of Stockholm, Sweden was that the anchor lines were completely covered with mussels down to about 15 m in depth. This can serve as an indication that lowering farm units may not necessarily result in reduced settling, slower growth or smaller biomass of mussels.[16] The two leading companies selling mussel farm equipment in Europe, Smartfarm and Kingfisher, are both at present developing equipment to enable lowering of the farm units below the sea surface and the ice.

Thus, assuming that ice conditions can be handled (e.g. through lowering the pipes and nets), the use of nets as substrate for settling and farming seems to work well for mussel farming in the Baltic.

Harvesting Technologies

The net farming technology that was used for the trials on the Swedish East coast requires, as do other similar systems, special equipment for harvesting. In the case of harvesting from nets there is a "farming catamaran" on the market that brushes off the mussels while the nets still hang in their pipes. The mussel biomass is then pumped on board and emptied into large sacks. This is a simple and effective system but requires quite a number of farms to harvest in order to be profitable.

There are also other farming technologies that rely on lifting the nets or farming substrates onto a harvester. As Baltic mussels have rather weak threads for attachment, there is a risk that quite a lot of the biomass may be lost using this technique.

Regardless of the method used, harvesting requires a steady work vessel with a large working deck and a powerful crane and winch of good capacity. Further, capacity to bring the harvest ashore as well as an infrastructure in the form of a dock, loading crane and transportation is necessary. Depending on the further use of the harvested biomass, it may be necessary to have short transportation/handling time in order to keep the mussels fresh and alive.

Environmental Assessment

Environmental Impacts

While their environmental preferences differ, there does not appear to be any significant difference in the environmental impacts from cultivating blue and zebra mussels. Important differences will be found in the environmental impacts as a result of the type of technology used for cultivation (e.g. vertical line systems, single long tubes, other) and the characteristics of the cultivation site (e.g. shallow, protected lagoon versus exposed, coastal site).

WATER QUALITY

In waters adjacent to a mussel cultivation area, bathing water quality is expected to improve as a result of increased water transparency resulting from mussel filter feeding activities. Mitigation against eutrophication is expected to occur as a result of nutrient removal.

There are also unfavourable impacts on benthic communities and on the biogeochemical cycling of nutrients immediately beneath the cultivation site. Increased sedimentation of organic matter from faeces is expected to increase benthic sediment oxygen uptake, which can lead to local oxygen depletion events and ultimately have a negative impact on the mussel production.[27] Increased sedimentation and sediment oxygen uptake can also lead to decreases in abundance and biodiversity of benthic communities as well as a deterioration of food web interactions between phytoplankton and zooplankton communities.[28]

Generally, excessive negative effects can be avoided if the sediment surface stays oxygenised, which also allows for the natural denitrification processes to continue. The denitrification is important as it leads to the transformation of different nitrogen substances, such as ammonium, into biologically inactive nitrogen gas.

In this context it should be mentioned that it is comparatively easy to monitor the effect of the organic sedimentation from a mussel farm on the benthic biogeochemical conditions and ecosystem.

Table 4: Overview of mussel cultivation impacts on environmental objectives and priorities.

Environmental Objective	Environmental Priority	Mussel Cultivation	Comments
Water quality	Bathing quality	🔵	
	Water transparency	🔵	
	Eutrophication	🔵	
	Biogeochemical cycles	🔴	Beneath the site
Habitat / Species protection	Food web dynamics	🔴 ?	Phyto-zooplankton interactions
	Biodiversity	🔴 🔹	Benthic communities & anoxia
	Benthic habitats	🔴 🔹	Anoxia versus shelter, food supply
	Bird habitats	🔵	
	Fisheries	🔵	
	Marine mammals	🟠	Depends on location
	Marine noise		
Coastal protection	Coastal morphology	🔹	
	Scenery	🟠	Depends on setup
Climate protection	CO_2 Emissions reduction		

🔵	strongly supportive
🔹	moderately supportive
🔴	strongly not supportive
🟠	moderately not supportive
○	neutral
?	gaps in information;
blank	not applicable

The most cost-effective and least time-consuming method is probably using a sediment profiling camera and related analysis technique.[29] Even more precise methods[30] are available for measuring the changes in benthic nutrient fluxes caused by the rich bio-sedimentation below a mussel farm and these may also be used in order to judge the overall effects of mussel farming as a remediation tool.

The extent to which these impacts counterbalance the positive effects the mussel farm can have on water transparency and nutrient removal adjacent to the site is still under debate.[28, 31, 32, 33]

HABITATS

Mussel farms may have an increasingly favourable effect on pelagic and surface biodiversity for fish and bird populations since they may act as floating reefs. On the other hand, the location of the mussel farm should take into account any migration routes of marine mammals and their potential to become entangled in a farm site or otherwise disturbed.

COASTAL PROTECTION

Mussel farms may modify local water movement, absorb energy and provide a form of coastal protection for vulnerable coastlines. The visual impact of mussel farm can however be a concern for local communities, in particular if the setting is particularly scenic. This very much depends on how the mussel farm is configured on the surface.

Suitable Sites

Careful site selection is essential in order to achieve sustainable mussel farming. According to existing

Figure 9: Examples of worst (*left*) and best (*right*) case scenarios for a mussel farm's visual impact. In the future, mussel farms will most likely be lowered subsurface, with negligible impact on the scenery. Pictures by Jens Kjerulf Petersen (*left*) and Odd Lindahl (*right*).

knowledge and experience with farming mussels in general and especially in the Baltic Sea, the selection of a farming site for blue mussels should be based on the following criteria:

HYDROGRAPHICAL FACTORS

- Small to moderate water currents
- No or infrequent occurrence of drift ice in winter
- Water depth of 10–30 m
- Salinity should not go below 4 PSU
- Normal bottom water exchange in order to avoid low oxygen benthic conditions

BIOLOGICAL FACTORS

- Good to normal occurrence of mussel larvae during the settling period
- Good to normal occurrence of phytoplankton (mussel food)
- Need to take marine mammal migration routes into account

LEGAL / PRACTICAL FACTORS

- The site must be in accordance with general and local regulations on area use
- Site area should be 1–10 ha
- Protection from heavy seas
- Access to the site during normal weather conditions
- No discharge or other source of harmful contaminants in the close surroundings
- No interference for waterways and only minor interference for recreation activities
- No or minor interference for fisheries
- No or minor to moderate interference for residents and visitors

These criteria need to be adjusted when applied to zebra mussel farming site selection, mainly since zebra mussel cultivations are restricted to enclosed coastal areas (lagoons or inlets). Therefore, they should also consider:

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

Overall, mussel farming as part of an integrated management plan that includes remediation measures addressing nutrient inputs at their source shows promise. What is clear for the prospect of Baltic Sea mussel farming operations is that careful site selection, use of appropriate technology and implementation of appropriate integrated management measures are keys to converging on an environmentally acceptable solution.

Furthermore, mussel cultivation as part of an integrated aquaculture system will have positive impacts by recycling nutrients and effectively treating waste effluent emanating from fish aquaculture (see "Sustainable Fish Aquaculture" Chapter).

- Water currents suitable for effective young settlement and particulate matter uptake, not exceeding 2 m/s
- Much lower water depth (e.g. for the Curonian Lagoon the suitable water depth is considered less than 2 m due to shallowness of the zebra mussel natural habitats).
- Salinity should not exceed 1.5 PSU with no or minimum abrupt salinity fluctuations

It is presently not possible to make a reliable estimate of how many sites and how big the total area that may potentially be available for mussel farming along the Baltic coasts and that meets the criteria given above. For blue mussels the possibility of utilising areas used for wind power generation may be an additional possibility, especially in view of the technical possibility of lowering the mussel nets. This concept should be further explored.

Socioeconomic Aspects

Costing the Nutrient Removal Effect

As a relatively new venture, mussel farming for nutrient removal is still characterised by a lack of available data with respect to production costs, mussel sales options for human or animal consumption or different growth conditions.

So far only one study has been undertaken estimating the value of mussel farms for combating eutrophication[34] by comparing it with costs related to alternative abatement measures such as a) increasing cleaning at sewage plants b) buffer strips c) wetland construction and d) cultivation of catch crops. The "value" of mussel farming as an abatement measure arises then from possible cost savings obtained by replacing other measures that have higher cleaning costs with mussel farming.

The study applied the replacement cost method to four areas in the Baltic Sea with different salinity levels resulting in four different scenarios: mussel farms with and without mussel sales options and with high and low mussel growth rates and meat content (nutrients) in the mussels. The study showed a strong relationship between the marginal cost for nutrient removal and these factors: Costs highly dependent on the mussel growth rate, which in turn is strongly connected to salinity. Connected to this is the ability to market the mussels as high-priced seafood or as less valuable products such as feedstuff or fertiliser.

In the given cases this meant that no marginal cost for nitrogen removal occurred along the Swedish West coast when the mussels were sold as seafood. The estimated marginal cost was about € 23 per kg of nitrogen removed when the mussels were used for feedstuff, whereas it was about € 35 per kg of nitrogen removed when only nutrient removal was valued and the harvested biomass was given no commercial value.

Of course the marginal costs are also affected by the choice of mussel farming technology, though in the given study only long line technology was considered.

Table 5: Estimated marginal costs using mussel farming for nitrogen and phosphorous harvest along the Swedish coasts. Data from Gren et al.[34] (US-$ converted into €.)

	Salinity level	**€/kg nitrogen**	**€/kg phosphorus**
Skagerak/Kattegat	↑	0–32	0–323
Öresund Strait		0–36	0–361
Southern Baltic		6–34	61–338
Northern Baltic		13–77	131–769

The same author of the above quoted study is currently involved in further developing cost estimates for mussel farms in the Baltic within the parallel running flagship project "Aquabest". Results are expected to be available in spring 2013.

Cost Factors in Mussel Farming

Table 6 shows the distribution of the various costs elements involved in building up and running a seafood mussel farm with a production capacity of 100 tonnes/year. It is based on cost estimates of a classical farm in western coastal areas of the Baltic Sea. The costs may of course differ quite substantially in other areas further eastwards and offshore mainly due to different technology needs (i.e. lowering nets in order to prevent ice damage).

In the table only a price is indicated if the mussels can be used for human consumption. This is indeed a growing market and high prices may be achieved also in future due to limited farming capacities to meet worldwide demands.

However, with Baltic Sea mussels mainly serving the potential market of feedstuff and fertiliser, it would be interesting to have an indicative price for these products. At the time of writing this compendium such price was not possible to be given. It can, however, be assumed that with growing demands for organic food (and related feedstuff) as well as an enormous market potential for fish meal the price

Table 6: Estimation of costs for a 100 tonnes production unit for food mussels.[35]

Equipment and other items	**Investment costs (€)**	**Depreciation (Years)**	**Annual cost (€)**
Longlines (5000 m)	5,000	5	1,000
Anchors and moorings	5,000	5	1,000
Markings	8,000	5	1,600
Buoyancy	15,000	5	3,000
Socks	2,400	1	2,400
Collectors	500	5	100
Vessel	150,000	5	30,000
Facilities on land			20,000
Machinery	45,000	5	9,000
Staff			125,000
Total costs	**225,900**		**193,100**
Estimation of profit		**€**	
Target price / kg of mussels		2	
Turn over of 100,000 kg		200,000	
Annual profit		7,500	

for such products to be developed from mussels may increase substantially in the future to come. In such case the cost and/or price, which would need to be paid for the nutrient removal, services of mussel farming could either be lowered or the business would simply become more profitable allowing for further (private) investments in development.

PUTTING IT INTO PERSPECTIVE

Despite these large variations mussel farming in all four scenarios was shown to cut costs in meeting stringent environmental targets. Calculated costs savings ranged from € 20–138 million.
Even more – when comparing the marginal cleaning costs of mussel farming with those of 20 alternative abatement measures in 24 different drainage basins of the Baltic Sea, it could be shown that mussel farming has a positive value for a large range of nutrient reductions.[28]

Political Strategies

Since mussel farming in general is a form of aquaculture, all political strategies and regulations related to the issue of sustainable aquaculture in the course of the EU's Common Fishery Policy apply to mussel cultivation as much as to fish aquaculture (see related chapter). It may be added that non-organically produced feed ingredients and thus also the non-organic share in fish meal was supposed to be banned by now through an EU Regulation (EEG 2092/91 and 1294/2005), but was subsequently changed in spring 2008 due to the difficulties of finding organically produced feedstuff containing enough of the amino acid.

The question is to what extent political strategies are in place, which support mussel farming as a compensating measure for nutrient discharges causing eutrophication. So far HELCOM does not list "mussel cultivation" as one of such measures (see also background chapter of this compendium). Nevertheless, the idea is already under discussion on the Åland islands. The Ålandic water act with its so-called "improvement surplus" allows fish farmers to increase their production when implementing compensation measures and the Åland government is further investigating this possibility within the Aquabest project. The need for the promotion and evaluation of mussel cultivation as a tool to reduce nutrients in the Baltic Sea and the Swedish West Coast is also already explicitly mentioned in the most recent Swedish Governmental White Paper 2010 "Measures for a Living Sea", which includes many aspects of the Maritime Policy Bill 2009, where the development of mussel farming on the Swedish East, South and West Coast was already mentioned. Moreover governmental grants for local water management projects improving the marine environment can also be used for such mussel cultivation measures. At present (autumn 2012), the design of a regulatory framework for environmental mussel farming is under development in Sweden, with the aim of being put into force in 2014.

REGIONAL CASES

Already by 2004 the small town of Lysekil (South West Sweden) managed to interpret the EC sewage directive in such way that the nitrogen removal of a sewage treatment plant could be replaced by mussel farming. The community bought this service from a mussel farming enterprise, which ensured that the nitrogen removal would take place. The cost of € 160.000 for the Lysekil Community was far below the costs related to the construction and running of a traditional nitrogen removal step within the sewage plant. On top current monitoring figures show that the mussel farm achieves almost 100% N-removal as opposed to the 70% actually requested by the EU directive. And even more so – also phosphorous is recycled back to land at no additional cost. However, due to some wrong conditions in the business plan the mussel farming enterprise went bankrupt and the project could not be completed.

Furthermore an interesting coupling, which has – however – not yet been applied for marine uses such as mussel cultivation, is to link rural development programmes to measures affecting eutrophication. Under the existing European agricultural environmental aid programme (EEC 2078/92 and 1257/1999) support has for instance been given for the establishment of wetlands, spring cultivation and catch crops in order to decrease nutrient released from farmland to the environment (see also background chapter). So far, however, this programme has been specifically designated only for farmland and does not include "farm water", i.e. aquaculture operations in the coastal zone.

Legal Aspects

Legal considerations relating to the start of a "mussel farm" in the Baltic Sea may differ substantially according to:

- Where the mussel cultivation is planned (country, region, municipality / coastal zone, territorial zone, EEZ) – and –
- What are the products of the mussel farm (i.e. human consumption vs. feedstuff / fertiliser; environmental service / nutrient removal)

Other aspects to be considered in approval procedures for mussel cultivation are:

- the Council Regulation (EC) No 708/2007 concerning use of alien and locally absent species / often requiring an environmental risk assessment to be carried out
- the Council Directive 2006/88/EC dealing with the control and prevention of diseases in the course of mussel farming

SWOT Analysis

STRENGTHS

- Environmentally friendly and flexible tool for improving eutrophic coastal waters by removing nutrients and improving water transparency, while at thee same time sustainably producing valuable marine protein that can be used in feeds and valuable fertilisers, especially for organic farmers
- Mussel farming is probably relatively cost-effective compared to other measures of combating eutrophication
- Utilises naturally occurring resources and returns discharged nutrients back to land in the form of valuable protein
- Regionally produced mussel meal can replace fish meal, hence contributing to the improvement of fish stocks
- Functioning as a floating reef, a mussel farm can lead to increased local biodiversity and suitable conditions for fish fry sheltering and feeding
- Potential to enhance the local small-scale recreational fishery
- Potential to create new jobs in rural coastal areas
- Areas used for wind and wave energy production may also be used for mussel farms
- May be a useful pedagogic tool for teaching environmental engineering

WEAKNESSES

- The brackish Baltic is not an ideal area for growing blue mussels due to the low salinity, which slows down growth and limits the size of the mussels
- May have negative environmental impacts on benthic bio-chemical processes and fauna below a farm
- Open coasts are too exposed for a mussel farm except if farms are lowered below the surface
- Mussel farming for environmental measures in the Baltic will be dependent on the mussel farmers being compensated for the ecosystem service provided
- Harsh conditions (severe winters and storms) may threaten to physically destroys the farms

OPPORTUNITIES

- Growing European and regional trends to combat eutrophication (e.g. EU Directives, HELCOM)
- Demand from organic farmers and aquaculture enterprises for sustainable feed
- Growing demand for improving coastal water quality
- Growing demand for developing innovative work opportunities for the coastal region population
- There are few other operational measures which can recycle nutrients from the coastal water back to land and also reuse them
- Development of offshore wind energy offering possibilities for combined installations

THREATS

- Mussel farming requires access to suitable farming sites, which may become increasingly difficult to find in coastal areas as spatial conflicts intensify
- Unclear political decision-making regarding how ecosystem service compensation should be performed and who will pay for the remediation
- Resistance of local populations to the new use of “their” coastal waters, regarded as navigational obstacles or ruined views
- Lack of complete consensus within the scientific community on the value of mussel farming as a measure to improve coastal water quality in the Baltic

Knowledge Gaps

There are still a number of knowledge gaps concerning mussel farming in the Baltic Sea, the most critical of which are:

- Assessment of legislation issues related to the implementation of mussel farming for water quality remediation in the different Baltic countries.
- Experience with submerged mussel farming technologies under Baltic conditions as well as technologies – different from the current longline technologies – more suitable for offshore cultivations
- More empirical research needed on growth of mussels, nutrient concentration under different physical environmental conditions
- More experience with harvesting and logistics of large-scale operations of mussel farming for remediation under Baltic conditions
- Possible locations of mussel farms from a large scale perspective
- What is the cumulative ecological impact on the Baltic coastal ecosystem of bio-engineering measures like nutrient recycling through farming and harvesting of mussels?
- What are the consequences for nutrient regeneration and biogeochemical cycling arising from increased sedimentation and sediment oxygen uptake in the less saline, eastern Baltic?
- Depth of knowledge on the economics of environmental mussel farming in the Baltic Sea.

Conclusions

Mussel farming has the potential to be a sustainable means of combating eutrophication provided it is part of an integrated management plan which includes remediation measures addressing nutrient inputs at their source and recycling of nutrients by using mussel harvest for feed production and fertilizer. Furthermore, there is a need to address at a political level, the issue of compensation for ecosystem services.

Given the above, mussel farming may become a new commodity and a commercially promising area for entrepreneurship, creating new businesses and jobs in rural coastal areas.

Beyond environmental remediation, there is a growing interest in using Baltic mussels for feed production and fertiliser. A risk assessment of farmed mussels from the Kalmarsund area in Sweden has clearly demonstrated that the concentrations of toxic elements and organic contaminants in the soft tissue and the shells are safely below the regulatory limits for use in both feed and fertiliser. Production of mussels for these end uses may thus have a substantial potential for growth. Especially the interest in making feeds based on Baltic Sea raw materials is increasing and feed trials with rainbow trout and arctic char are ongoing. Further, feed trials on organic livestock of pig, layers and chicken, where mussel meal of Baltic origin is used as a high quality protein source (replacing fish meal) will be carried out during autumn 2012.

Current technologies such as the use of nets or long-lines as substrate for settling and growth seem to already work well for mussel farming in the Baltic Sea, though future mussel farms in the region will have to be able to manage ice during winter, especially drifting ice.

Recommendations

It should clearly be pointed out that the first option concerning the leakage of nutrients from different kind of human activities shall always be to perform actions as close to the source as possible. However, from numerous of experiments and trials it is clear that nutrient discharge through myriads of point and diffuse sources under foreseeable time will continue to leak and overfeed coastal waters with nutrients. Once the nutrients have reached the coastal water, there are only a few alternatives available in order to collect, harvest and recycle these nutrients. Mussel farming is one such method, which has been shown to have a potential to recycle nutrients from the sea back to land in the Baltic Sea Region, but still is under development and testing to be used under Baltic conditions.

Therefore, it is recommended to further support the technical development of farming mussels in the Baltic as an environmental measure for improving coastal water quality as well as for the important recycling of nutrients according to the Agro-Aqua nutrient recycling principle:

- Phosphorous should be recycled because this element will in the future be lacking as seen on a global scale.
- Nitrogen is energy demanding and climate driving to produce and should therefore be reused.
- Agriculture operations are responsible for a large part of the nutrient discharge into the Baltic. Using mussel farming as a remediation tool may bring these nutrients back as valuable feed components or as an organic fertiliser.
- A robust and sustainable system for financing and paying for the nutrient recycling enterprises is absolutely necessary if mussel farming and similar eutrophication abatement methods should become a reality.

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Reed Harvesting

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THE COMMON REED (*PHRAGMITES AUSTRALIS*) IS A PERENNIAL GRASS, which grows best in shallow fresh or brackish (somewhat salty) water. It is often the key species in wetland ecosystems and usually forms dense stands called reed beds.

Reed shoots can reach up to 4 m in height, sometimes even higher. The leaves are up to 50 cm long and 2–3 cm wide.[1] The flowers are produced in up to 50 cm long panicles or clusters.

Reed reproduces mainly vegetatively (asexually) by rhizomes and it is one of the most productive plant species in the world. The size of a single reed bed can vary remarkably, occupying hundreds of hectares in favourable conditions. Reed can colonize new areas at a rate of several meters per year, which makes it extremely competitive compared to many other plant species.

Reed can be harvested regularly, for example every second year. Harvesting does not have any negative or positive impacts on the reed's ability to reproduce.

Figure 1: Common reed (*Phragmites australis*) in Turbuneeme, northern Estonia in January 2007 (left) and in Tooraku, western Estonia in July 2011 (right). (Photos by Ü. Kask)

The Rediscovery of Reed as a Renewable Resource

Introduction

With shallow bays and lagoons offering ideal conditions for growth, large coastal areas along the Baltic Sea are covered by reed beds. Common reed has been used for different purposes since ancient times. These uses include construction, biofuel, feed for the people and fodder for the cattle or raw material in cellulose production. Over the past centuries these traditional uses of reed have diminished remarkably, particularly in construction, where stone buildings with hard inflammable roofing have replaced thatched reed ones but also in other applications.

More recently, however, reed has been rediscovered as a useful resource to address growing needs related to environmental and climate change concerns. Such new uses include reed as a resource for energy production including biogas and bioethanol as well as nutrient removal from water systems and post-treatment of wastewater. Whereas the latter is already commercially feasible, the use of reed as a bioenergy resource is still mainly in an experimental stage.

Even though reed beds have diminished in size in some areas due to regular grazing of livestock or reshaping of coastal zones, the overall area of reed beds throughout the Baltic Sea Region has increased very rapidly during the last 150 years. Factors contributing to this expansion have been the increased input of nutrients into the water bodies, which favours reed growth, as well as the designation of many wetlands as nature reserves with consequent decrease in mowing and grazing.

Currently it is not possible to make a precise assessment of the overall size of reed areas and their respective biomass throughout the Baltic Sea Region. Since reed can increase its area very rapidly if overall conditions are suitable and enough nutrients are available, a proper inventory can only be done on the basis of continuous monitoring. Such an observation system is, however, for the time being still missing.

While reed is sometimes regarded as a nuisance (i.e. as weed in surface water bodies), the maintenance of reed beds has a high environmental as well as cultural value since they provide important habitats for a number of species, act as a protection against coastal erosion and offer aesthetic enjoyment. It is thus understood that any kind of harvesting must take these factors into account. In most countries, strict regulations are already in place to preserve reed areas and thus the overall biomass available for applications in the field of nutrient removal and bioenergy remain be limited.

Reed in the Baltic Sea Region

Environmental Requirements and Productivity

Large parts of the coastal area along the Baltic Sea offer optimal conditions for reed as it can only grow in shallow waters, with reed-dominated communities prevailing usually in water depths below 0.3 m. The low salinity level of the Baltic Sea also favours reed growth, which shows optimum growth in salinity with concentrations ranging between 0–15 PSU.

Availability of nutrients and high soil fertility will usually increase the number, height and weight of shoots. Excess nitrogen, in particular, can considerably increase reed productivity, with lots of nutrients being stored in rhizomes in summer and winter, which facilitates rapid growth in spring. Maximum shoot biomass decreases from south to north. Whereas reed typically produces an aboveground dry weight biomass of 1000 g/m^2, only 300-400 g/m^2 are achieved in the northern part of the Baltic Sea Region. The chemical composition and physical properties of reed can also vary substantially across the region. The biomass of summer reed is usually higher due to shoot mortality and leaf shedding.

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

Despite the limited availability of reed beds with potential for harvesting, it would be a mistake to underestimate the potential of these reed-based applications as a contribution to regional solutions especially for environmental remediation and renewable energy.

Table 1: Reed aboveground biomass in various areas of the Baltic Sea Region.

County / Region	Average yield in dry matter (tonnes/ha)
Estonia	7.4–9.1
Curonian Lagoon (Lithuania)	5–40
Niedermoor (Germany)	12–20
Hirvensalo (Finland)	5–12

Reed Bed Areas

As a result of the favourable conditions provided by the Baltic Sea, reed can be found in many of its coasts, growing at the interface between marine and terrestrial environments. The exact area of reed and its spatial distribution is, however, difficult to estimate as not all countries carry out an annual inventory of reed areas and their biomass. Moreover, the area of reed is quite variable and can change a lot during a year depending on such factors as natural expansion rate, ice conditions during winter, changes in grazing practices or reed cutting. Furthermore, unclear transitional zones between marine and terrestrial environments make the mapping of reed bed areas rather challenging.

Overall, however, it is evident that reed bed areas have increased very rapidly in some parts of the Baltic Sea Region over the past 150 years. The area of reed beds in Matsalu Bay (Estonia) increased from 10 km^2 in the 1870s to 30 km^2 in 1983.[2] While in some parts of the Baltic Sea coast red beds are on the wane as a result of efforts to reshape the coastal areas combined with regular grazing of livestock, overall the increases in reed bed areas across the region have been more significant.

A rough inventory (figure 2), which may partially also include reed beds located in lakes, estimates that the total area of reed in shallow bays and coastal lagoons of the Baltic Sea exceeds 300,000 ha. Sweden has by far the largest resources. Large reed beds can also be found in Finland and Estonia. Data about the reed bed areas along the coast of Denmark was not available.

Figure 2: Rough estimate of reed areas in shallow bays and coastal lagoons of the Baltic Sea (no data available for Denmark).

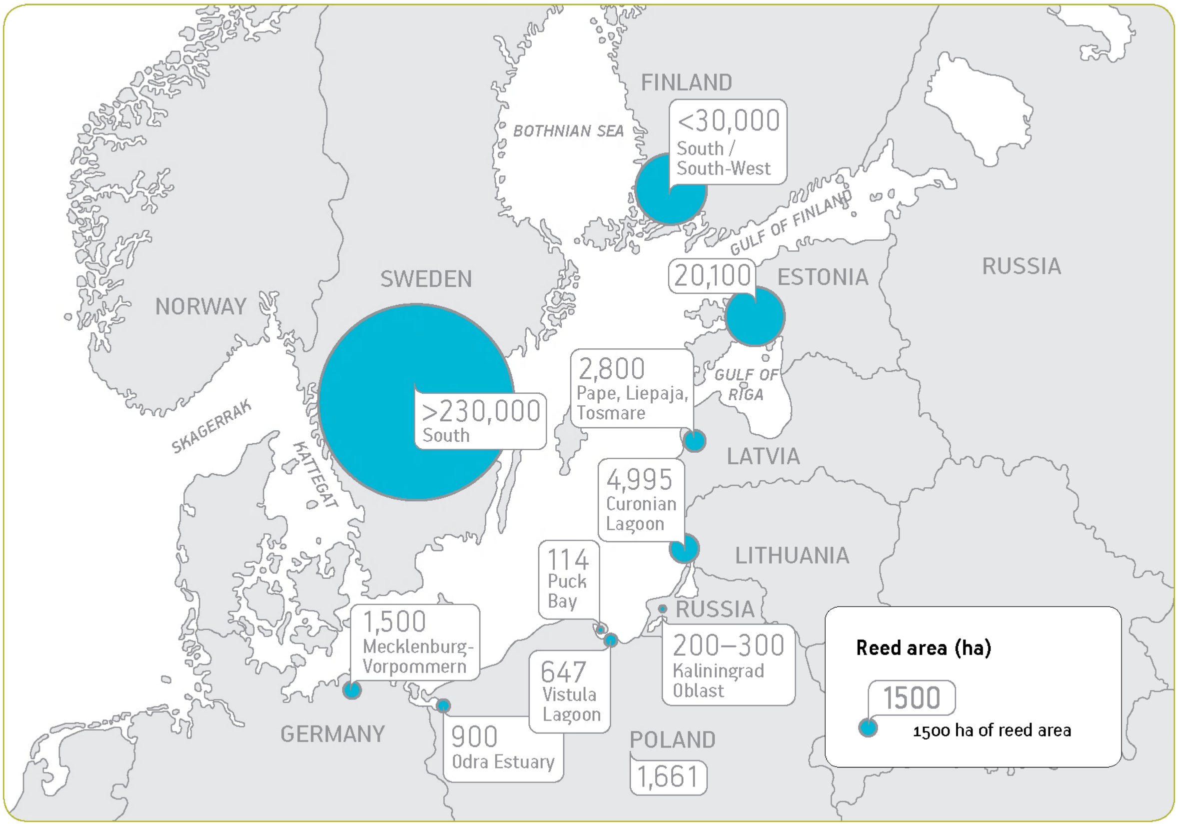
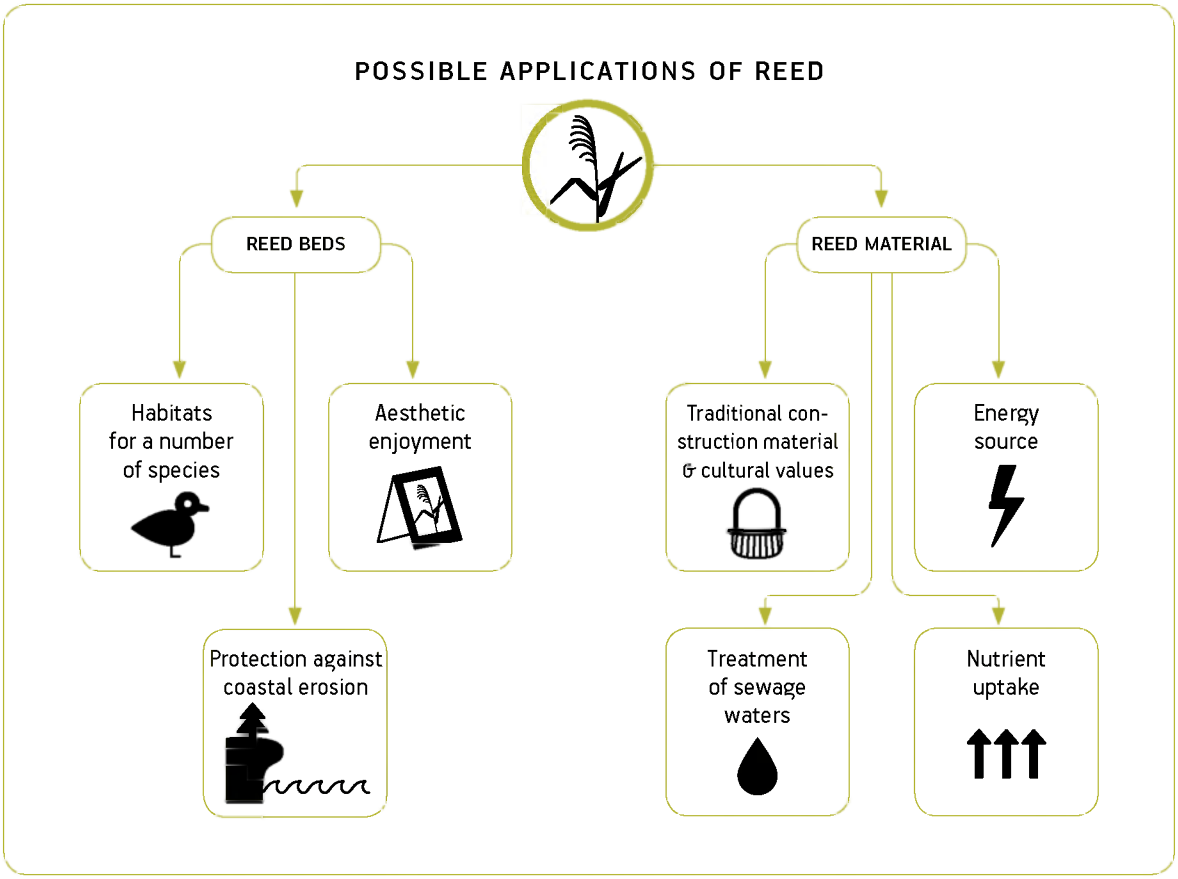


Figure 3: Possible applications of reed.



Applications

With changing needs and growing concerns due to environmental pollution and the search for new energy resources, reed has recently been rediscovered as a possible resource for new types of applications ranging from water treatment to bioenergy (figure 3).

Construction Material

THATCHING MATERIAL

In most of Europe, straw and reed thatch remained, until the late 1800s, the only roofing material available for most of the population in the countryside and in many towns. Gradually, however, thatch became a mark of poverty and the number of thatched properties declined when other roofing materials came on the market. Today, reed roofs have become a status symbol in some of the richer countries.

Thatch roofs are easy to repair and the roof supports do not need to be heavily constructed as a dry reed roof is very light, weighting only about 30–40 kg/m^2 depending on the thickness. Reed roof longevity depends on reed quality, reed length and the slope of the roof. The northern side of the roof, which is usually covered with moss, can last longer than the southern side, where the impact of UV radiation diminishes the quality of the top reed cover. A good quality reed roof – which will last at least 50 years – should have a slope over 45° so that water flows faster and the roof dries faster. The oldest reed roofs in many countries are more than one hundred years old.

INSULATION MATERIAL

Wider utilization of reed as an insulation material is a rather recent phenomenon, especially at the greater distances from the sea, aiming to replace artificial "non-breathing" insulation materials by a renewable, ecological material. Reed is used to cover walls, ceilings or as frost insulation for floors, usually in the form of reed panels known as Berger panels, which are industrially produced. Reed is a good lathing for clay or cement plastering. The required quality of reed for wall panels can be lower and the length more variable than of reed used as thatching material. Sufficiently compacted panels (180 kg/m^2) improve the fire safety and are not easily flammable. The thickness of compacted panels will not exceed remarkably the thickness of other materials such as mineral wool for an equivalent thermal insulation.

Renewable Energy Sources

Biomass is one of the most important renewable energy sources in the world. The demand for energetic utilization of biomass is increasing enormously and is often supported by governmental regulations. Whereas the overall biomass of common reed is too limited to serve as a substantial renewable energy resource, it can nevertheless be counted as a promising biomass source at local scale in some coastal municipalities and coastal areas.

Table 2: Calorific value of common reed in comparison with other fossil fuels and solid biofuels. (Data from Barz et al., 2006,[3] modified)

Feedstock (dry matter)	**Calorific value (MJ/kg)**
Hard coal	31.8
Brown coal	27.0
Pine wood	18.7
Wheat straw	17.1–17.3
Grain straw	17.5
Rape straw	17.0
Common reed	**17.5–17.7**

COMBUSTION

Reed has a calorific value comparable to other plants species and solid biofuels including wood (table 2).

The calorific heating value of reed is very much determined by the moisture content and that depends on the harvesting season.[4] A study (Ü. Kask, unpublished) in six coastal counties in Estonia revealed that the theoretical primary energy content of winter-harvested reed makes it suitable for combustion. The energy content is somewhat lower at moisture content of 20 % which is typical during the harvesting period from January to April (table 3). The total primary energy content of summer harvested green reed silage is much lower (205 GWh) and, therefore, it is more suitable for anaerobic digestion to biogas. Also, the ash content is lower in

Table 3: Theoretical and typical (at moisture content of 20%) primary energy content of winter-harvested reed in Estonian coastal reed beds (by Ü. Kask, TUT).

Area of reed beds	**Average yield 2006-2011**	**Theoretical primary energy content[1]**	**Typical primary energy content at moisture content of 20%[1]**	**Estimated amount N**
20,059 Ha	5-11.8 tonnes/ha	575.58 GWh	463.79 GWh	up to 1.2 tonnes/ha

1 – Calorific value of dry matter of winter reed is 4.9 MWh/t and of reed with moisture content 20%–3.94 MWh/t

Figure 4: Reed pellets (left) for combustion and hay and reed storage at a boiler house (right). (Photos by Ü. Kask)

winter (2–4%) than in summer (4–6%) reed and so is the nitrogen content.

In the case of combustion plants located far away from the coastline, the reed material has to be condensed in order to be able to transport the required biomass. This can be done by pelletizing, baling or briquetting the reed (figure 4), but is, of course, an additional cost factor.

BIOGAS PRODUCTION

Experiences using reed for biogas production as well as information on its yield are rather limited. Experimental study results from Tallinn University of Technology revealed that the biogas yield of summer reed is about 140–190 m^3/t (Ü. Kask, unpublished), which is comparable to methane yield from crops or crop residues (e.g. maize silage) and different macroalgae species (See “Macroalgae Harvetsing and Cultivation” chapter). The calorific value of biogas is approximately 6 MWh/1000 m^3. Jagadabhi et al. reported a methane yield of 220–260 m^3/t of reed in laboratory-scale reactors.[5] Laboratory experiments carried out in Kalmar municipality in Sweden also provide a methane yield of about 220 m^3/t from co-digestion of reed.[6] It has been estimated that the reed beds in Gotland, Öland and Kalmar municipality in Sweden could give up to 10 GWh of biogas energy from an available 5670 tonnes of reed biomass.[7]

The excess sludge from the biogas production can be used as organic fertilizer. The sludge of reed harvested from 5 ha and used for biogas production would theoretically satisfy fertilisation requirements of up to 2–4 ha of farmland on an annual basis assuming that about 60% of the nitrogen and nearly 100% of phosphorus in the reed biomass can be re-circulated.[6] However, only summer reed can be used for production of biogas as winter reed is too dry and the nutrient content lower, which diminishes methane digestion by the bacteria.

BIOETHANOL PRODUCTION

Similarly to biogas production only few experimental studies have been carried out on the use of reed for production of bioethanol. So far these have, however, shown positive results. A joint Portuguese-Hungarian study has led to the conclusion that the conversion process to bioethanol *per*

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

In the Baltic Sea Region, the total available biomass of summer reed is limited, as harvesting is often in conflict with the services provided by reed as a habitat.

se does not present any major obstacles and the very high biomass yield of the reeds makes them candidates for potentially replacing currently used crops for commercial bioethanol.[8] Another study showed that the glucose yield of common reed is similar to silage and much higher than sunflower.[9]

Removal of Nutrients

Reed beds are efficient in removing excess nutrients from shallow coastal waters due to their high biomass and extensive underground rhizome systems, which can extend to a depth of up to 35 cm. Indeed, wetlands have been extensively utilised in the last decades to clean polluted waters almost all over the world.

The potential for nutrient removal by the plants is, of course, finite unless the accumulated nutrients are removed by harvesting the reed. The content of nutrients in reed varies remarkably in different years, seasons and locations. The average nutrient content of summer reed (in leaves, stems, roots and panicles) varies usually from 1 to 3% of nitrogen (N) and 0.14 to 0.2% of phosphorus (P). Aboveground winter-harvested reed contains 3–4 times less nitrogen compared to the summer reed.

Most nutrients are stored during the beginning of the growing season. Thus, the highest amount of

PUTTING IT INTO PERSPECTIVE

A Tangible Nutrient Removal Effect?

Usually about 50–100 kg of nitrogen and 5 to 10 kg of phosphorus per hectare can be removed from a water body by harvesting the aboveground part of the reed, assuming a mean annual biomass yield of 5 tonnes/ha. Harvesting of 50,000 ha of naturally growing reed in Sweden would represent an uptake of approximately 1,500 tonnes of nitrogen and 150 tonnes of phosphorous.

Based on the most optimistic scenario, harvesting of reed provides about 1 % of N and about 3 % of annual P reductions in the Baltic Sea Region, based on the target levels set up by the HELCOM Baltic Sea Action Plan.

ADDITIONAL POINT

The Case of Curative Mud

In some parts of the Baltic Sea Region, reed is found in areas where the bottom mud of the water bodies is defined as curative. Curative mud is a natural substance that comprises therapeutically active compounds (salts, gases, bio-stimulants) and living microorganisms. It is used for health care purposes and as an ingredient in cosmetic products especially in the Baltic States.

There are large mud reserves in Estonia, Latvia and probably in other countries but more precise information about their availability in the Baltic Sea Region is lacking. The deposits are not designated as a resource yet and require further studies.

In order to protect curative mud deposits, economic activities including reed harvesting have to be prohibited in these areas. Since it is very likely that the demand and excavation of mud will increase in the future, this aspect should be considered when planning for the use of reed.

nutrients could be removed from the system if the reed were collected in early summer. This is, however, also the bird nesting period and reed cutting is often not allowed.

Wetlands can reduce nutrients also by enhancing denitrification in anaerobic sediments that returns N_2 back to the atmosphere and by encouraging sedimentation and uptake of phosphorus in the sediments.

The main benefits of using reed beds for removal of nutrients are the low capital and operating costs: a reed bed can last many years with hardly any labour or energy requirements.

Competence Centres in the Baltic Sea Region

The list of competence centres (table 4) contains mainly research institutions engaged in reed management such as cultivation, production, usage and utilization. It does not include business companies who supply and sell the reed or provide services for e.g. thatching or energy producers due to their large number and variety in the Baltic Sea Region.

Table 4: Overview on competence centres in the Baltic Sea Region

Nr.	Institution	Contact person	Description	Webpage
1	University of Greifsweld, Institute of Botany and landscape ecology	Prof. Dr. Hans Joosten	reed cultivation (paludiculture)for energy generation	www.botanik.uni-greifswald.de
2	Michael Succow Foundation for the protection of Nature	Dr. Wendelin Wichtmann	reed cultivation	www.succow-stiftung.de/home.html
3	The Rural Economy and Agricultural Society of Halland	Peter Feuerbach	Wetlands and biodiversity (reed usage for energy generation)	www.wetlands.se
4	Royal Institute of Technology (KTH), Division of Industrial Ecology	Fredrik Gröndahl	reed cultivation and usage	www.kth.se/en/itm/inst/industriell-ekologi
5	Swedish University of Agricultural Sciences, Department of Forest resource management	Johan Svensson	National inventory of landscapes in Sweden (mapping of places of reed growth)	www.slu.se/en/collaborative-centres-and-projects/nils/design
6	Southwest Finland Environment Centre	Iiro Ikonen	Reedbeds management and utilization	www.ruoko.fi/index.php?page=english
7	Aarhus University, Department of Bioscience – Plant Biology	Hans Brix	Reed growth and cultivation	pure.au.dk/portal/en/hans.brix@biology.au.dk
8	Tartu University, Department of Geography	Ülo Mander	Use of reed for waste water treatment plants (WWT)	www.lote.ut.ee/geo/yldinfo
9	Tallinn University of Technology, Department of Thermal Engineering	Ülo Kask	usage of reed as energy source	www.ttu.ee/faculties/faculty-of-mechanical-engineering-1/home-6

Nr.	Institution	Contact person	Description	Webpage
10	Tallinn University of Technology, Department of Environmental engineering	Arvo Iital	research about usage of reed as a resource, impact of harvesting of reed on water quality	www.ttu.ee/ehitusteaduskond/keskkonnatehnika-instituut-4
11	UAB Senasis ežerlis	Dr. Aušrys Balevičius	research about usage of reed as a resource	www.senasisezerelis.lt/?set_lang=en
12	State Ltd. "Vides projekti"	Aija Zučika	properties of reed pellets for energetic use	www.videsprojekti.lv

Technology

Harvesting Technologies

Different technologies for harvesting reed are widely in use and commercially available. The choice of a suitable technology depends on the resources, use, cost-efficiency, season as well as environmental regulations. However, the impact of different harvesting methods for reed beds, water quality, fish and bottom fauna is so far not well studied.

The selection of technologies depends on the following factors:

- Aim of reed cutting (further use or getting rid of excess reed)
- Type of further use of reed
- Size of reed beds
- Environmental conditions, e.g. salty or fresh water, muddy or hard bottom, season (cutting on ice or in the water)
- Environmental impact and related national regulations, e.g. contact pressure per unit area of harvesters and transport vehicles
- Available resources (costs)

Quite simple technologies can be used when aiming just for clearance and maintenance of coastal areas and control of reed plants, such as hand-held cutter bar mowers, cutters mounted on small boats, engine-driven mowers or amphibians.

Amphibians can have certain advantages compared to heavy tractors because they exert less ground pressure and damage. Therefore, harvesters like the commonly used Seiga often use low ground pressure balloon tires to minimize impact on the bottom and rhizomes if harvested during summertime (figure 5).

Industrial production of reed as a construction material or for biofuel requires more sophisticated technologies that include tractors, cutters and platforms to collect and transport the reed. Some harvesters can chop the reed into chips, which can be then pressured into pellets for bioenergy use.

Figure 5: The Seiga harvester. (Photo by G. Bethlen)

Technologies for Construction

Technologies for construction have actually not changed a lot over the past centuries and still involve substantial handwork. The reed suitable for construction must firstly be sorted and cleaned from leaves, too short straws and panicles. Suitable reed straw must be straight and not too thick (maximum 8 cm). Reed bundles used for roofing should usually be 62-64 cm in circumference and 100–200 cm in length.

Technologies for Energy Production

Different technologies for energy production are available, partly commercially and partly only at experimentally, especially when it comes to biogas and bioethanol production.

The simplest process for winter reed is to make round or square bales and burn them in applicable furnaces of boilers. But suitable machines are also on the market for pressing reed into pellets (Decive Agri 20) or larger briquettes (RL-50BM of Taiwan SK Machinery). The primary energy content of one 400 kg bale is about 1.5 MWh at a moisture content of 20%, whereas the average calorific value of reed pellets and briquettes is 4.5–4.6 MWh/t.

The burning of reed bales requires equipment that is also suitable for the combustion of straw bales (straw packages) and other herbaceous fuels. The capacity of this equipment usually does not exceed 0.5–0.8 MW and the annual average efficiency is not higher than 70%. The equipment is usually relatively inexpensive.

The bales of herbaceous biomass (packages) can also be used in larger boiler plants (combined heat and power plants, also know as CHP plants) where they are transported into the furnace with the respective feeders (figure 6). The capacity of this equipment reaches 4–6 MW. Another option involves the preliminary shredding of the bales and transport of crushed reed into the furnace either with a screw conveyor or by blowing it in with forced airflow. Reed biomass shred to a suitable size can be burned in the mix with fossil fuels or wood fuel and peat.

For burning the pressed fuel pellets, specialised burners and furnaces are used (figure 7). Usually the capacity of this equipment remains in the range that can be used for heating a single-family house (10–100 kW).

Anaerobic digestion to achieve reed biomass conversion has been applied only in experimental facilities in the Baltic Sea Region, as there is not enough biomass available due to restrictions on harvesting green summer reed, which is the only reed resource usable for biogas production.

Figure 6: Transporter (left) and combustion chamber (right) of the facility for burning crushed (scarified) straw and reed. (Photos by Ü. Kask)

Figure 7: The stocker burner. (Photos by EcoTec (left) and Ü. Kask (right))

Dry digestion of crops with total solid content of up to 50 % – including reed – in one-stage reactor systems requires lots of water for homogenization and energy for pumping, mixing and heating. Therefore, for optimization of anaerobic digestion a two-stage process consisting of separate reactors for hydrolysis and methanogenesis is recommended.

REGIONAL CASES

The industrial use of reed for energy production started in Estonia in 2010, where an old oil burner was replaced by a Danstoker biomass burner (1.8 MW) aiming to use local hay, straw and reed resources as well as wood residues. The annual energy production of the facility is 4.2 GWh and it uses about 1,000 tonnes of hay and reed plus 200 tonnes of wood chips annually. The new technology decreased both the CO_2 and SO_2 emissions by 98 %. The price of the energy for the consumers also decreased from € 57.71/MWh in 2010 to € 54.96/MWh in 2011.

Environmental Assessment

Environmental Impacts

Reed beds provide important ecosystem services in the areas of water quality, biodiversity, coastal morphology, climate protection and scenery. If carefully managed, reed harvesting has the potential to further contribute to some of these ecosystem services through an increase in the capacity of the reed bed to remove nutrients, through resource efficient and renewable construction materials and through the production of bioenergy from harvested biomass.

For a sustainable approach it is, however, necessary to maintain a balance between the natural ecosystem services reed beds provide and developing the potential of reed beds to contribute further to ecosystem services.

The environmental priorities that are impacted by harvesting reed are water transparency, eutrophication, biogeochemical cycles, food web dynamics, biodiversity, benthic and bird habitats, fisheries, coastal morphology, scenery and climate protection (table 5).

WATER QUALITY

The extent to which reed beds can improve water quality is dependent on how often and when the reed is harvested as harvesting is the only way to permanently remove nutrients from the system.

Due to seasonal restrictions limiting the harvesting of reed to winter, the amount of nutrients that can be removed from the system is lower than if the harvest took place in summer. Summer removal is not an option as it has adverse impacts on such priorities as bird habitats. The potential for nutrient removal is limited[10] unless the accumulated nutrients are removed and plant shoots harvested.[11] Reed beds are also intrinsically linked to important biogeochemical processes occurring within the sediments of the coastal reed bed system.

HABITAT / SPECIES PROTECTION

They also provide important habitats that maintain and promote biodiversity. The impact that disturbance of these systems may have on biodiversity and food web stability remains an open question. Reed is a good competitor and stress tolerator. Mowing it may have a positive impact on biodiversity by increasing other species' ability to compete. The burning of reed has been carried out in many locations and probably in all countries specifically to increase the competitiveness of other plant species and to get rid of reed as a nuisance. Furthermore, renewal of the biomass

Table 5: Overview of reed harvesting impact on environmental objectives and priorities.

Environmental Objective	**Environmental Priority**	**Reed**	**Comments**
Water quality	Bathing quality		
	Water transparency	🔹○	Summer harvest needed, conflict
	Eutrophication	🔹○	Summer harvest needed, conflict
	Biogeochemical cycles	🔵🔴?	
Habitat / Species protection	Food web dynamics	🔵🔴?	Competitor / stress tolerator
	Biodiversity	🔵🔴?	Competitor / stress tolerator
	Benthic habitats	🔴○	Only if harvested in spring/summer
	Bird habitats	🔴○	Only if harvested in spring/summer
	Fisheries	🔴○	No impact if harvested in winter
	Marine mammals		
	Marine noise		
Coastal protection	Coastal morphology	🟠	
	Scenery	🟠	
Climate protection	CO_2 Emissions	🔹	Carbon neutral – energy

🔵 strongly supportive
🔹 moderately supportive
🔴 strongly not supportive
🟠 moderately not supportive
○ neutral
? gaps in information;
blank not applicable

can have a favourable impact on biodiversity by providing new food for dependent communities. However, the disturbance itself may damage fragile communities and lead to a decrease in biodiversity. Further research is needed.

Most reed beds in the Baltic Sea Region are located in protected areas including Natura 2000 sites. The impact of harvesting reed on bird, benthic and fish habitats is potentially very significant and is the main area of concern for this activity (table 6).

A number of issues need to be considered in this respect:

- Resident and migratory bird populations and the timing of the breeding season
- The type of technology to be used, as this is important in determining the impact harvesting will have on benthic communities
- Resident fish populations and their dependence on reed beds as nursery grounds

The negative impacts harvesting reed may have on these communities may be minimised if mowing takes place during winter. However, the best timing to mow within this seasonal window remains an open issue, in particular with respect to the impact timing may have on the status and development of the reed area and its wildlife.

COASTAL PROTECTION

Reed beds provide environmental services through coastal protection, stabilizing river banks and erosion control. In addition to the timing of the mowing season, a good knowledge of the regional coastal dynamics is critical to ensure that any issues related to coastal protection and storm damage are considered. Changes to coastal morphology may also impact local scenery.

Table 6: Restrictions on reed harvesting in cases where it disturbs protected bird species.

SUMMER HARVEST	WINTER HARVEST
Negative	**Positive**
• Serious disturbance on the environment, such as bird breeding areas. • Rhizomes can be destroyed by the harvester, which decreases reproduction of the resource in the following year • Cutting below the water surface could substantially inhibit the re-growth of shoots. • Harvested material requires energy-consuming drying, unless the material is used for biogas production.	• No serious environmental disturbance occurs. • Destruction of rhizomes can be prevented if harvesting is done from ice or on frozen soil. Increased spring light and diminished harmful effects of parasites could even provide better conditions for reed growth. • Reed is more dense • No need for drying to reed before use as fuel or construction material.
Positive	**Negative**
• Highest amount of biomass availability (i.e. as renewable energy) • Only wet summer reed is suitable for biogas production. • Highest effect on nutrient removal.	• Represents only about 50% of the yearly above-ground biomass. • Reed is thinner. • Only small amounts of nutrients are removed from the system, as most of the nutrients are recycled to the rhizomes.

CLIMATE PROTECTION

The potential to apply resource efficiency methods to construction material and produce bioenergy from harvested biomass can make a favourable contribution to climate protection. However, the extent to which this may be significant is not known. Bioenergy production from reed contributes at least to some extent to the reduction of CO_2 emissions (and other greenhouse gases) since reed is considered to be carbon neutral.

Seasonal Considerations

The most serious concern arising from harvesting reed is the impact it may have on protected areas for nature conservation, in particular nesting birds, fish and benthic habitats, especially if harvesting takes place in the summer. Thus, harvesting often has to be limited to specific seasons only. It also has to consider the overall carrying capacity required to allow reed beds to function as suitable habitats and must ensure the use of appropriate harvesting technology in order not to damage the ground.

Socioeconomic Aspects

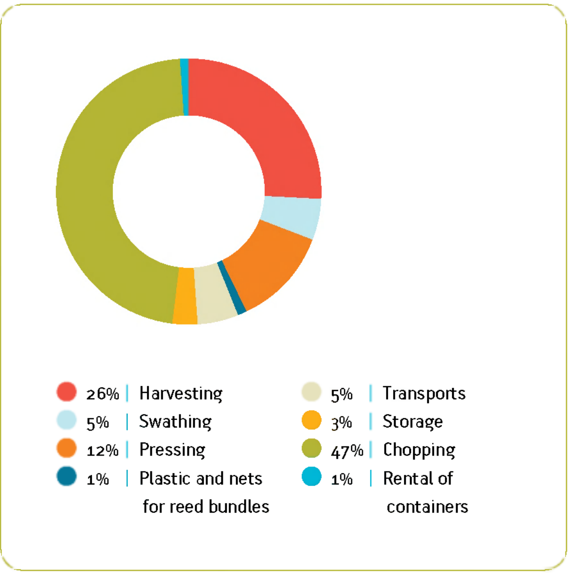
It is difficult to provide a proper cost-benefit analysis for mowing, harvesting, transport, drying and storage of reed. Whereas a monetary value can be associated to reed as a natural resource (e.g. the value of reed as a roofing material, as biofuel for energy production or for the treatment of sewage waters), it is difficult to estimate the environmental, cultural and aesthetic services provided by the reed and reed beds (e.g. maintenance of biodiversity, water protection, climate benefits). Generally it is evident that a sustainable use of reed resources is only feasible, if all possible services provided by the reed and reed beds have to be taken into consideration as well as the willingness of society to pay for the maintenance of reed bed areas. Even then, however, it might only be an option in certain areas as also costs vary substantially within the Baltic Sea Region, depending on used technologies, labour costs and harvesting season.

Cost Drivers

The economic efficiency of reed use depends on technological developments related to harvesting, production, transportation, conversion, etc. A socio-economy study of reed harvesting in the Kalmar Region (SE) has shown that especially harvesting and chopping of the reed are very expensive and that methods used so far are not efficient (see figure 8). Mowing and harvesting of reed are seasonal work and direct costs are related to employee's salaries, varying substantially between countries. Also costs e.g. for drying and storage buildings and maintenance of machinery can vary depending on the location, season, machinery used, etc. Only costs for machinery including oil, gas, amortization or rent is more or less the same in different regions.

Study results from Germany[13] provided that the sum costs of reed harvesting (variable and fixed

Figure 8: The estimated cost of different activities in the process chain: Chopping of the reed is the most expensive stage and must be developed in order to get a good economy. Harvesting is the second most costly activity and may also be improved. Data from Blidberg, Aldentun and Gröndahl.[12]



costs, including costs for land) using a combined harvester and tractor with varying acreage performance for transportation of medium biomass yields (8 tonnes of DM/ha) varies from € 276 to € 406 per ha and € 35–€ 51 per t DM.

Transport and storage costs highly depend on the amount of reed to be driven and/or stored and the density of the biomass. The bulk density of chopped reed is very low (approx. 32 kg/m^3), whereas by baling, the density can be increased to 140-170 kg/m^3. Both transport as well as storage costs can be reduced by compaction of the reed by baling, briquetting or pelletizing. The cost for transport of bulk material varies from nearly € 80 per tonne if the distance is 50 km to nearly € 170 per tonne for 150 km and much cheaper (€ 7–15 per tonne) for pellets.[14] Transport costs of reed bales are somewhere in between. However, baling costs can constitute nearly half of the overall harvesting costs (up to € 110 per ha). A study by Eder et al. (2004, cited after Wichtmann & Tanneberger, 2009[13]) provided reed transport costs for a distance of 30 km that is from € 9 to € 27 per t DM depending on the compaction level (bales, chops or bundles) of reed.

REGIONAL CASES

Labour Costs for Harvesting Reed in Estonia

Assuming daily labour costs of € 80/day/employee, total annual labour costs will be:

4 workers × 252 days × € 80/day = € 80,640

The quantity of biomass Q harvested in a year considering the capacity of a Seiga harvester (9.1 tonnes per hour) and actual harvesting time (630 hours) is:

$$Q = 9.1 \text{ t/h } 630 \text{ h} = 5733 \text{ tonnes}$$

The labour costs for harvesting reed per biomass tonne (C_{ton}) will be:

$$C_{ton} = € \, 80.640 \, / \, 5733 \text{ t} = € \, 14.06/\text{t}$$

Costs for the machinery, its amortization, oil and maintenance are not accounted.

Benefits and Price Drivers

The price that can be obtained for harvested reed highly depends on its quality as well as its expected use. The price of reed as a building material is usually higher than that of reed destined for energy production, but construction also requires higher quality reed. Current market price for reed end products for construction varies from € 1.5–2 per bundle (2.5 kg) and is sufficient to cover the production costs, at least in some parts of the Baltic Sea Region. However, transportation costs are high and thatching is labour intensive and requires skilled work and is thus costly.

Prices to be achieved for reed as a resource for energy production vary from € 12 to € 20 per MWh depending on the quality of the material (e.g. moisture content), the grade of processing needed for combustion as well as prices achieved by other comparable energy resources, i.e. straw, wood chips, etc.[15]

In case of reed for energy, the given current market price is not sufficient to cover production costs unless an economic value could be attached to the environmental services associated with it. Reed harvesting does not only lead to reduction of nitrogen and phosphorus, but also to savings in CO_2 emissions. In a Finnish study it is estimated that one hectare of reed bed represents about 2000 litres of light oil and thus a saving of 6 tonnes of CO_2 emissions,[15] whereas a Swedish study[12] shows an 80% reduction of carbon dioxide in comparison to a fossil based fuel. Furthermore, frequent harvesting could reduce the amount of methane (greenhouse gas) emitted by reed beds to the atmosphere.

Table 7: Cost-benefit analysis (€ per tonne reed in wet weight) for the production chain when harvesting 180 ha or 2,700 tonnes reed. From Blidberg, Aldentun and Gröndahl.[12]
Please note: different values for nutrient reduction refer to two different methods of socio-economic valuations: the willingness to pay method[16] (low figures) and the marginal cost method[17] (high figures).

Scenario	**Costs (€ per tonne reed wet weight per year)**	**Benefits (€ per tonne reed wet weight per year)**
Market value		
Reed harvesting, including chopping and other activities in the process chain	373	
Biomethane production	48	
Biomethane sales		49
Fertilisers		0
Total sum for monetary costs and benefits:	422	49
Valuation of ecosystem services		
Nutrient uptake		
Nitrogen		16 / 137
Phosphorus		77 / 406
Recreation and aesthetics		40
Reduction of green house gases		4
Reduction of particles		4
Total sum for ecosystem services	0	141 / 591
Total sum for all costs and benefits:	422	190 / 640

Regulatory Framework

If reed is considered for its capacity for nutrient removal and renewable energy production, its harvesting can be seen as contribution to respective environmental regulations and action plans such as the Marine Strategy Framework Directive[18] and Helcom's Baltic Sea Action Plan.[19]

On the other hand, reed harvesting is restricted in all Baltic Sea countries due to environmental regulations aiming to protect biodiversity such as the Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, the Council Directive 2009/147 on the protection of birds as well as restrictions set by the designation of Natura 2000 areas, which often include large parts of the coastal sea.

None of these directives recognises the common reed as a species that requires protection. However, in some coastal areas reed beds can be seen as valuable habitats for birds and other species that require protection.

In addition to these regulations numerous countries have developed specific recommendations for reed harvesting (table 8).

Table 8: Seasonality aspects in planning reed harvesting and use.

Country	Harvesting Area	Harvesting Season
Denmark	10-20% of reed area or at least 3 ha must be left untouched 10-30 m wide untouched strip of reed must be left in the outer part of the reed bed area	No harvesting after 28th February
Sweden	50 to 50 m large parcels inside the harvested area should form a mosaic of used/unused reed areas 40 m wide untouched strip of reed must be left in the outer part of the reed bed area	No harvesting after 28th February
Finland / Estonia	In some areas, at least 20 ha of untouched reed bed must be left as nesting area of bittern in Finland	No harvesting after 15th March
Latvia	Protection and use regulations depend on the individual area	No harvesting after 31st March

SWOT Analysis

STRENGTHS	WEAKNESSES
• A traditional / common of Baltic Sea Region renewable and natural resource • New opportunities such as energy production (biogas and bioethanol) as well as nutrient removal from natural water systems and post treatment of wastewater • Variety of applications providing multiple means of using reed with different quality (including using leaves and panicles) • Relatively cheap as taxation of the resource is not applied and reed is not accounted as a resource • High value ecosystem regulating services (removal of nutrients) at low capital and operating costs: a reed bed can last many years with hardly any labour or energy requirements • Combustion of pure reed or as a mixture in biomass does not contribute to greenhouse gas emissions • Reed's calorific value is comparable to that of other plants species/solid biofuels, including wood	• Information on annual reed biomass is rarely available • The use of reed as a bioenergy resource is still mainly at an experimental stage • Lower heating value compared to fossil fuels • Calorific heating value of reed very much dependent on the harvesting season • Limited information available on the economic efficiency of bioenergy production • Insufficient technical solutions for efficient and economical reed harvesting • Hampering transportation costs (optimally transportation should not exceed 50 km) • The reed resource can be limited. Therefore, energy production usually requires combined use with another kind of biomass • Nutrient content in reed varies remarkably in different years, seasons and locations • Harvesting is limited to specific seasons only • Potential conflicts with recreation, fishing and nature protection if wrongly exploited

• Reed cutting for production of roofing material and/or for energy improves access to waterways and visibility and contributes to the removal of excess nutrients from water systems	• High price of machinery for mowing and handling of reed • Shortage of skilled employees who could utilise the material efficiently
OPPORTUNITIES	**THREATS**
• Growing demand for energy from alternative sources • Growing prices for traditional energy carriers • EU support in the form of energy and climate change policies structural funds • Growing development in high technology • Global drive towards sustainable development • Growing support for decentralised network economies	• Worsening Baltic hydro-meteorological conditions due to climate change • Potentially increasing nature protection requirements (protection of coastal wetlands) • Decrease in straw quality for thatching due to increasing use of nitrogen fertilizers that weaken straw and reduce its longevity • Elevated nitrogen input to coastal wetlands due to climate change and increasing water runoff, will lead to too fast growth of reed and decreases it's quality needed for construction • Lack of political support at national level in the form of national energy policies ensuring a stable level of energy prices from renewable sources • Lack of public support • Lack of financial support due to the actual economic and financial crisis

Knowledge Gaps

Reliable data on the reed areas and their biomass in the Baltic Sea Region is still missing. Therefore, further studies and monitoring are needed.

Further research, in particular from the ecosystem perspective, is required in a number of areas to underpin any sustainable management plan for the exploitation of the resource. These include:

- A better understanding of the impact of reed harvesting on biodiversity and food web stability.
- A better understanding and quantification of the potential benefit (if any) to climate protection resulting from the application of resource efficiency methods and bioenergy production.
- Mapping of suitable areas for harvesting and use of summer reed

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

There is a need for a better understanding of the complex interactions between different environmental priorities and the impact reed harvesting may have on them. Any exploitation of reed beds should be underpinned by a sustainable management plan of the resource.

Conclusions

Reed is among the most productive plant species in the Baltic Sea Region due to high annual production per unit area. The quality of reed and its biomass vary significantly, which largely determines its suitability for different uses. Rapid expansion of reed beds often causes problems with the inventory of reed areas and their biomass.

The total area of reed in shallow bays and coastal lagoons of the Baltic Sea is at least 300,000 ha. The total annual biomass of the aboveground part of common reed that can potentially be used along the coasts of the Baltic Sea is up to one million tonnes, though the resource is quite unevenly divided. Different uses of reed require choosing between suitable harvesting times and methods as well as accounting for competition with other uses or cumulative effects (table 9).

The total energy potential of aboveground part of reed in the Baltic Sea Region is about 3.5–11 TWh assuming that the average calorific value of reed with moisture content of 20% is 3.9 MWh/t. Not all of the annual yield of reed can be harvested. Therefore, the total annually usable resource constitutes no more than one third of the aboveground biomass in the Baltic Sea and can actually be much lower (15–20% of the total biomass) in protected coastal areas. Therefore, the real energy potential of reed along the Baltic coasts is no more than 4 TWh and can be lower considering that part of the reed resource will be used as a construction material. In theory, it would be possible to satisfy annual energy needs for about 100,000 households assuming an average annual energy requirement per household of 30 MWh.

Experiences with using reed for biogas production are rather limited. Winter reed is too dry and the content of nutrients is lower compared to summer reed, which diminishes methane digestion by bacteria. Therefore, only summer reed can be used for production of biogas. There are also very few experimental results available on the use of reed for production of bioethanol, although a study[9] has revealed that the glucose yield of reed can be rather similar to that of silage.

Table 9: Seasonality aspects in planning reed harvesting and use.

Uses	Suitable Season for Harvesting	Comments
Thatching	Winter	Moisture content is lower. Less damage to the rhizomes and other biota, especially if harvested on ice.
Combustion	Winter	Moisture content is lower. Low quality reed as well as leaves and panicles can be used. Primary energy content of winter harvested reed is higher compared to summer harvested reed. Less damage to the rhizomes and other biota especially if harvested on ice.
Production of biogas and bioethanol	Summer, early autumn	Green biomass is needed for anaerobic digestion. Low quality reed as well as leaves and panicles can be used. Harvesting in summertime is problematic due to environmental impacts (e.g. bird nesting period, other biota, damage to rhizomes).
Harvesting for nutrient removal	Early summer	Nutrient content of reed is at its maximum. Harvesting is problematic due to environmental impacts (e.g. bird nesting period, other biota, damage to rhizomes).

Reed beds can be considered as an effective method to remove excess nutrients from shallow coastal seas due to their high absorption potential for macronutrients, especially nitrogen. Usually about 50–100 kg of nitrogen and 5–10 kg of phosphorus per hectare can be removed from the natural water system by harvesting the aboveground part of the reed assuming that the mean annual biomass yield of reed is 5 tonnes/ha. Thus, about 5,000–10,000 tonnes of nitrogen and 500–1,000 tonnes of phosphorus can be eliminated from the coastal sea annually assuming that the harvested area of reed is 100,000 ha, i.e. one third of the total reed bed area along the coasts of the Baltic Sea. Based on the most optimistic scenario, harvesting of reed provides about 1% of N and about 3% of annual P reductions, compared to the target levels set by the HELCOM Baltic Sea Action Plan. More nutrients can be removed from the system if reed is collected in early summer.The large variation in reed biomass yield data available as well as the differences in chemical composition and physical properties of reed highlights the need for further studies about reed productivity and environment friendly utilisation.

Recommendations

- Proper inventory and monitoring of reed resources (area and biomass) is needed at the scale of the whole Baltic Sea Region
- More research is needed to investigate the impact of reed harvesting on biodiversity and food web stability as well as its potential contribution to climate protection
- More research is needed on how to improve technologies for reed harvesting and production of reed based fuels
- Possible commercial uses of reed and environmental services provided by reed beds should be kept in mind when developing coastal zone management plans
- Autumn harvesting should be an option in the southern part of the Baltic Sea Region when aiming for nutrient removal
- Summer harvesting should be considered if aiming to use the reed as a source for biogas production
- Policies promoting wider use of biofuels should be adopted in all Baltic Sea Region countries
- Public awareness raising initiatives to promoting reed utilisation opportunities should be undertaken
- Discussion on nutrient trading performance, including remediation payment schemes and rules, should be undertaken in the Baltic Sea Region or the EU

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Large-Scale Microalgae Cultivation

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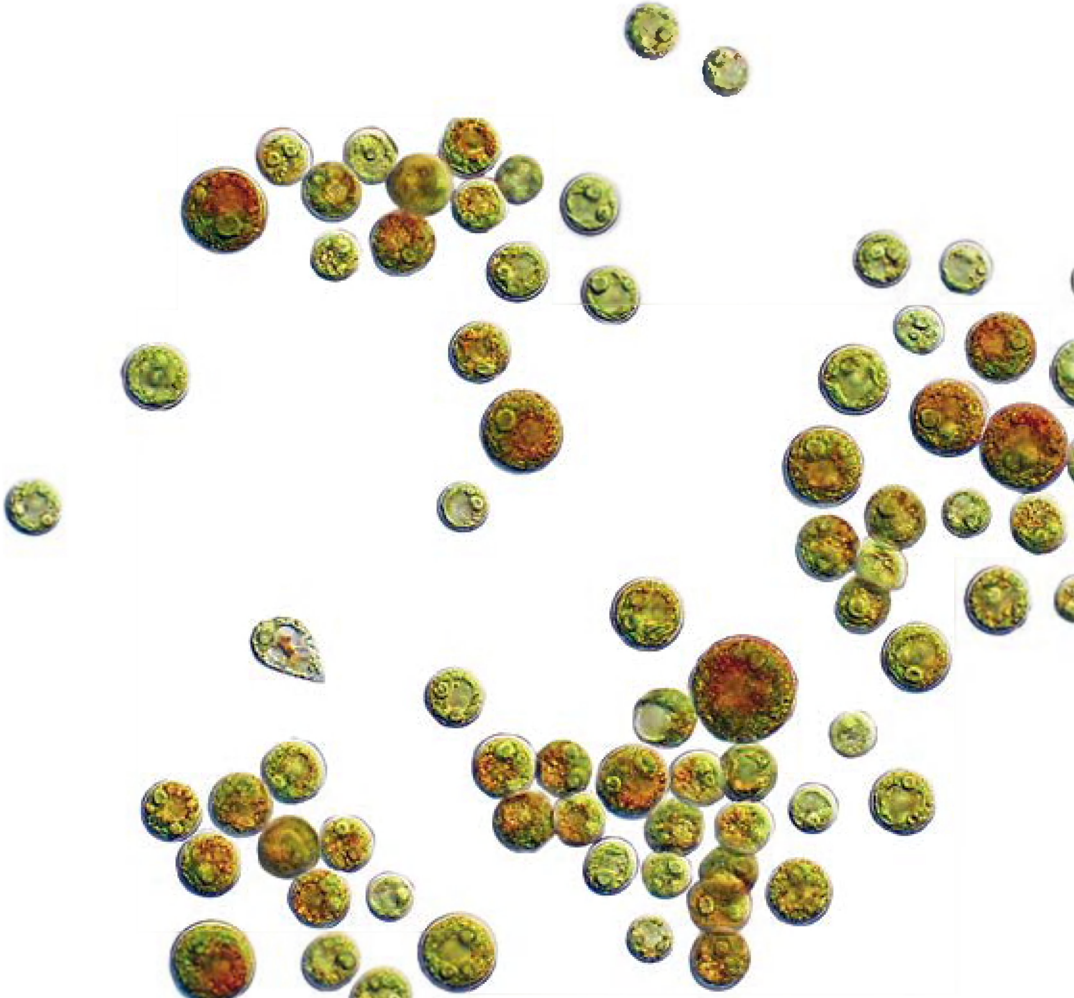
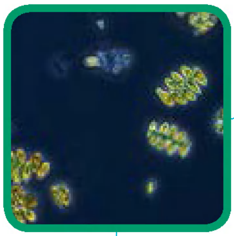




MICROALGAE ARE MICROSCOPIC ORGANISMS: the size of their cells varies from approximately 1 to 100 micrometers (μm). They are ubiquitous and fast growing and they live either floating in the water (known as phytoplankton) or attached to surfaces. Genetic and physiological diversity of microalgae is far greater than for higher plants.

Most microalgae are photoautotrophs, they use sunlight as a source of energy and CO_2 as a carbon source. In addition, they require nutrients like nitrogen, phosphorus and iron for growth. Microalgae contribute to 40–50% of the global primary production and are important drivers for global nutrient and energy cycles.

A promising alternative to land plants

Introduction

The use of microalgae biomass has been very limited until recently. The reason for this is that naturally occurring microalgae are found in very low densities in the water, even during bloom conditions. To obtain higher microalgae concentrations for biomass production, microalgae need to be cultivated.

Early pilot studies dating back to the 1950s provided general background information on the cultivation of microalgae and on their physiology. The Aquatic Species Program (1978–1996), funded by United States Department of Energy, was an all-inclusive research project advancing the knowledge on algae physiology, cultivation technology and use of algae biomass as an energy source. As a major outcome this project stated that although technically possible, algae biofuel production was not economically competitive during the mid 1990s.[1]

Currently, the microalgae cultivated worldwide amounts to more than 5,000 tonnes of dry weight and has an approximate commercial value of € 1,250 million.[2] The prices of most microalgae-based compounds and products are relatively high and the production volumes still small Thus there has not been pressure to minimise the algae cultivation costs, which are still much too high for production of low-value bulk products like biofuels.

However, scenarios of decreasing production costs in the near future – through technological development, selection of microalgae strains and molecular engineering, manufacture of co-products, up-scaling of production facilities and provision of other services like nutrient removal – suggest that in 10–15 years the price of algae-based biofuels may become competitive with fossil fuels.

One of the current challenges in the cultivation process is that fertilisers and CO_2 must be added to the culture media, which causes both economic and environmental concerns. The biorefinery model, which combines the production of low and high value compounds, ecosystem services and other industrial actions as well as the use of waste streams for providing algae with nutrients and CO_2, might offer potential solutions.

In the Baltic Sea Region microalgae biofuel production could contribute to nutrient recycling and to the reduction of greenhouse gas emissions as well as to energy security in times of decreasing fossil fuel resources. In addition, it responds to needs for food security as microalgae can be cultivated on non-arable land and thus does not compete for land with conventional agriculture. Furthermore, oil production from algae can be much larger than oil production from crop plants (e.g. rape seeds) and the cultivation area needed is much smaller thanks to higher productivity.

However, climatic characteristics of the Baltic Sea Region, such as seasonality in solar irradiance and temperature, may limit the growth of microalgae and thus the success of their cultivation. On the other hand, the availability of CO_2 and nutrients as well as skilled labour, transport modes and facilities for downstream processing of the biomass are considered positive aspects for microalgae cultivation in the region.

Microalgae Cultivation in the Baltic Sea Region

Microalgae Cultivation Requirements

For large-scale cultivation of microalgae, local species should be prioritised. These species are already adapted to climatic conditions and the risk of spreading alien invasive species decreases. There are around 1,000–2,000 microalgae species identified in the Baltic Sea but the actual number may be much higher. Only a few of those have been studied in detail for large-scale production.

There are various requirements for the species that may be used for large-scale cultivation production. These species should:

- Be easily cultivable and tolerate well suboptimal growth conditions (like light, pH, temperature and salinity).
- Be relatively resistant to viral or bacterial attacks.
- Have a life cycle that is not complex.
- Show high growth potential.
- Show ability to grow to high biomass.
- Accumulate high content of desired end products (e.g. lipids).
- Not be harmful, e.g. toxic.

It is not very likely that there exists one "super-species" which has superior traits and is suitable for cultivation in every location but various species for cultivation in different locations or with different cultivation technologies must be found independently.

In addition to the species chosen, the location is also of enormous importance for large-scale outdoor microalgae cultivation. In this regard, several regional aspects should be taken into account:

- Solar irradiance
- Temperature
- Precipitation/evaporation
- Severe weather conditions
- Water availability
- CO_2 availability
- Nutrient availability
- Land availability
- Availability of skilled personnel
- Cost of labour and other services
- Transport facilities
- Downstream processing of biomass
- Markets for main products
- Socioeconomic stability
- Legal aspects

While solar irradiance and temperature tend to be more unfavourable in northern Europe, these regions also have good availability of CO_2, nutrients, skilled labour and transport.[4]

Temperature and Light Availability

Sunlight is essential for microalgae growth. However, photosynthesis cannot utilise sunlight at 100 % efficiency. Theoretically, at maximum 9–11 % of the energy content of sunlight may be stored as chemical energy using photosynthesis. In reality, the efficiency is much less and values of 1–5 % seem realistic.[5] The efficiency is especially low at high light conditions and microalgae growth typically saturates at 10–20 % of full sunlight.

At first glance, areas in the high latitudes with long, dark and cold winter seasons like the Baltic Sea Region seem rather suboptimal for large-scale microalgae outdoor cultivation. Under clear sky conditions the annual average of sun energy for the region is 2,500–3,000 Wh m^{-2} per day, which is

ADDITIONAL POINT

HARVESTING OF NATURAL MICROALGAE

In addition to microalgae cultivation, technically the possibility also exists of harvesting natural microalgae. The concentrations of algae biomass during natural blooms may be 0.5–5 g of carbon per m^3 or 1–10 g of dry weight per m^3, thus approximately 1,000 times less than obtained through cultivation. For this reason, the harvesting of natural microalgae stocks is difficult to carry out in an economically viable way.

Microalgae growth season starts in spring, with the increase of light levels. During the summer months, blooms of filamentous cyanobacteria occasionally accumulate on the Baltic Sea surface, hampering the recreational use of the sea. There have been attempts to protect vulnerable beaches using special fabrics that allow water exchange but keep large filamentous cyanobacterial colonies from entering the area. However, in these cases the biomass is not collected.

Figure 1: Summer bloom in the Baltic Sea (picture: Jeff Schmaltz, NASA Visible Earth).

The removal of cyanobacteria in open Baltic Sea areas using modified oil booms was tested during a pilot study[3]. Based on these trials, roughly 5–10 ha of sea area could be cleaned in an hour, using a 50 m oil boom with a dragging speed of 2–4 km per hour. With the effective depth of 1 m, this amounts to a maximum clearance of 100,000 m^3 per hour. Based on realistic cell concentrations during blooms, the amount that may be harvested is 1–350 kg dry weight per hour, or roughly 0.5–175 kg carbon per hour.

Because filamentous cyanobacteria may contain toxins and are typically low in lipids, their use as feed, fertiliser or as a source of biodiesel is not realistic. Instead such biomass, if collected, should be used as feedstock in biogas plants. However, even though harvesting wild cyanobacteria may remove considerable amounts of nutrients from the sea, the biogas production potential of the collected biomass is rather low compared to harvesting costs.

approximately 50–66 % of the energy available in the middle of Spain or 40–50 % of the energy available in the middle of the Sahara desert. Of course, the seasonal variations are much larger in the Baltic Sea Region than at lower latitudes and it is obvious that the dark winter season is not suitable for growing any photosynthetic organism.

The projected areal production of microalgae at latitude 60°N (in the middle of Baltic Sea Region), ranges from 8 to 40 g of dry weight m^{-2} per day during the summer months based on the availability of light energy from the sun and realistic energy losses during microalgae photosynthesis (using photosynthetic efficiencies from 1 % to 5 %). When integrated for the whole year and considering an algae oil content of 30 %, the projected annual microalgae oil production at latitude 60°N ranges from 3.2 to 16 tonnes of oil per ha. This is considerably larger than the oil yield obtained with rapeseed (0.8 tonnes oil per ha).

Temperature also affects the enzymatic processes in the microalgae cells and thus growth. Often temperatures around 20–30 °C are considered optimal. However, some microalgae are adapted to grow at extreme temperatures. For example, in the Baltic Sea, microalgae spring blooms can start when the water temperature is as low as 2–4 °C and the growth rate of these species may exceed one division per day. As lipid producers, cold water microalgae species from the Baltic Sea do not differ from the rest of the studied species and they may accumulate large amount of lipids (>30 % of dry weight).[6]

The seasonality of microalgae production in Baltic Sea Region, based on irradiance levels, is pronounced and the question remains what fraction of the year the production may be economically feasible. Low temperature may also constrain microalgae cultivation unless species with low temperature tolerance are used.

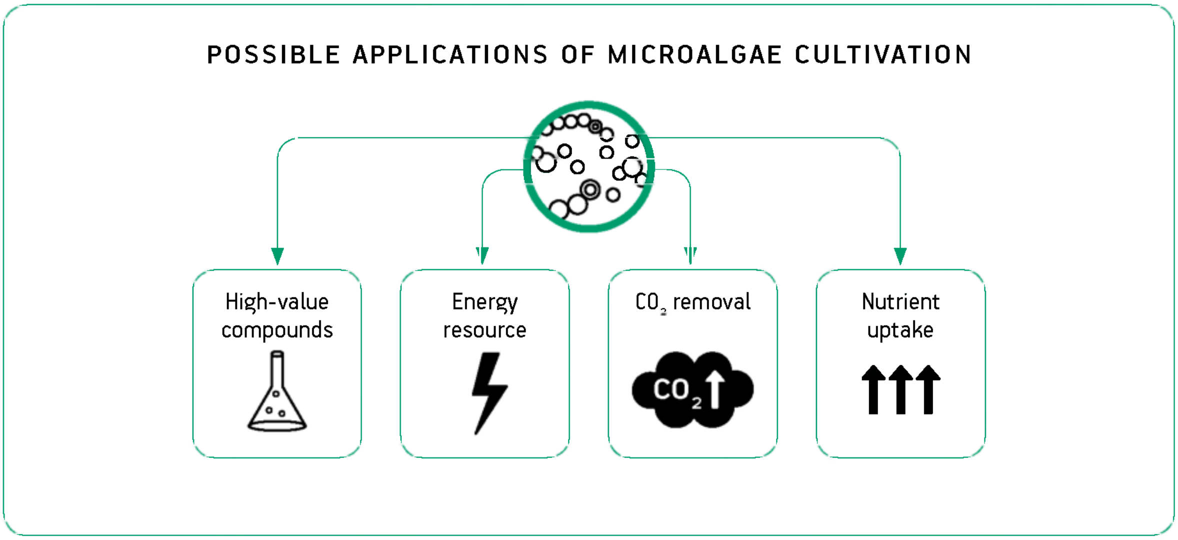
Availability of CO_2 and Nutrients

Microalgae cells contain roughly 50 % carbon (C), 4–8 % nitrogen (N) and 0.5–1 % phosphorus (P) per dry weight. In large-scale cultivation, these elements must be supplied at low cost; the use of pure CO_2 or fertilisers is not economically feasible.

The use of CO_2 from flue (exhaust) gas as a carbon source for microalgae has been widely studied and seems technically feasible. Several small-scale tests or pilots exist in the Baltic Sea Region. Ongoing research aims to discover if flue gas contains components that are toxic to microalgae, how efficiently microalgae can use the CO_2 in the flue gas and what the technical solutions are. Theoretically, very large amounts of CO_2 could be available from flue gas for large-scale algae culturing in the Baltic Sea Region (see box). The critical questions are whether it is technically achievable to combine these activities and whether it is legally, economically and societally possible.

Concerning the availability of nutrients, industrial, urban and agricultural wastewaters may provide nutrients for microalgae cultivation though the quality varies depending on the source and season. Various tests with microalgae species show that municipal wastewaters contain required nutrients for algae growth and generally do not contain growth-inhibiting agents.

Figure 2: Applications of microalgae cultivation.



Applications

Microalgae can be used for production of high-value metabolites, such as food additives, animal feed, drugs and cosmetics (see chapter on Blue Biotechnology). Also, microalgae cultivation may be used as a method for nutrient removal. Most importantly, however, microalgae are considered as a potential and sustainable carbon neutral source for biofuels for the future.

Microalgae Biomass as an Energy Source

High reproduction rates and accumulation of lipids with high-energy content make microalgae an interesting alternative to land plants in the production of biodiesel (figure 3A). For example, the estimates for areal lipid production of microalgae exceed those for the most productive land plants by a factor of ten, at a minimum. Despite recent emphasis, traditional oil crop plants (e.g. oil palm, rape seed) cannot significantly displace fossil fuels, as there is not enough arable land available. Projected areal requirements of microalgae are much smaller due to higher production potential and the fact that they do not require fertile soil (figure 3B). Additionally, unlike traditional farming, microalgae cultivation is feasible using saltwater and waste nutrients.

As an alternative to biodiesel, microalgae biomass rich in carbohydrates and proteins can be fermented to bioethanol or to biogas. Additionally, some microalgae species may produce hydrogen gas that may be used as an energy source in the future.

CO_2 Removal from Flue Gases

In natural waters, microalgae are not limited by the supply of carbon, as the decrease of CO_2 due to photosynthetic uptake by the microalgae is balanced by the exchange of CO_2 in the air-water interface. In dense cultures, however, this exchange is not rapid enough and the growth of the cells becomes carbon-limited. To circumvent this, cultures must be bubbled with CO_2. As an interesting alternative to purchased CO_2, microalgae may utilise CO_2 from exhaust from power plants. This gives microalgae cultivation value as a method for reducing CO_2 emissions.

This potential for CO_2 capture using microalgae has been getting increasing attention. The biofixation of carbon could be coupled with Carbon Capture and Storage (CCS) technology, which aims to "bury" the sequestered carbon (i.e. by burying all

Figure 3: Production of biodiesel from plant oils and algae oils.

Figure 3A: Biodiesel (l/ha/year).

Algae potential to produce oil is much larger than for plants, as indicated by production of oil per cultivated area (l/ha/year).

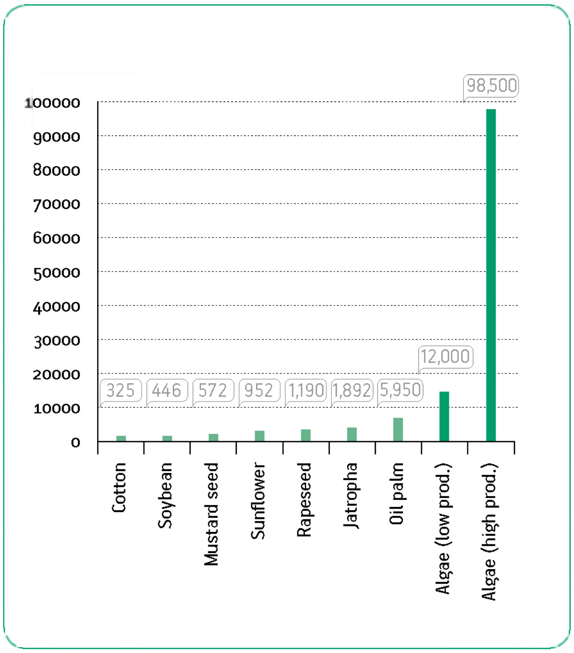
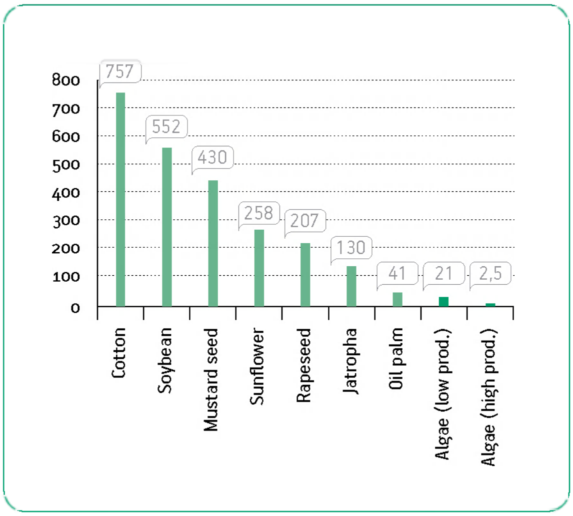


Figure 3B: Area required to produce global oil demand (as % of global arable land.

The area required, as percentage of the global arable land, to replace global oil demand using biodiesel. Two different scenarios for algae are shown: low productivity (dry weight productivity of 10 g m^{-2} d^{-1} and oil content of 30 % of dry weight) and high productivity (dry weight productivity of 50 g m^{-2} d^{-1} and oil content of 50 % of dry weight). Values are taken from Schenk et al.(2008).[7]



or part of the microalgae biomass), to produce a carbon negative energy source, a unique selling point for this approach.

If the carbon is not stored, the CO_2 captured in the biomass will eventually be released again once the biomass is burned or decomposed and will offer no permanent storage. However, the capture of carbon will increase the retention time of CO_2 and if used as bioenergy, more energy will be extracted per unit CO_2 emitted.

Nutrient Removal from Waste Streams

Another important benefit of microalgae is its potential in the treatment of wastewaters from urban, industrial or agricultural sites, thus reducing nutrient flows into the Baltic Sea. Although some contaminants in wastewaters may hamper the use of residual algae biomass for products such as feed, it can be used for biofuel. The challenge to achieve this will be to demonstrate the economic viability of such a system at the site of the waste production.

Analyses have already been made of the sustainability of microalgae wastewater treatment plants in cold climates.[8] Results showed that algae-based solutions may be more sustainable and in line with socio-ecological principles than conventional treatment plants, especially if algae based co-products can be generated and if nutrients can be re-circulated back to use. However, the analysis also noted that algae-based solutions require more land area partly due to the need for storage pond capacity, which is required for storing wastewaters during low productive winter months. No large-scale pilot tests have yet been conducted in the Baltic Sea Region.

REGIONAL CASES

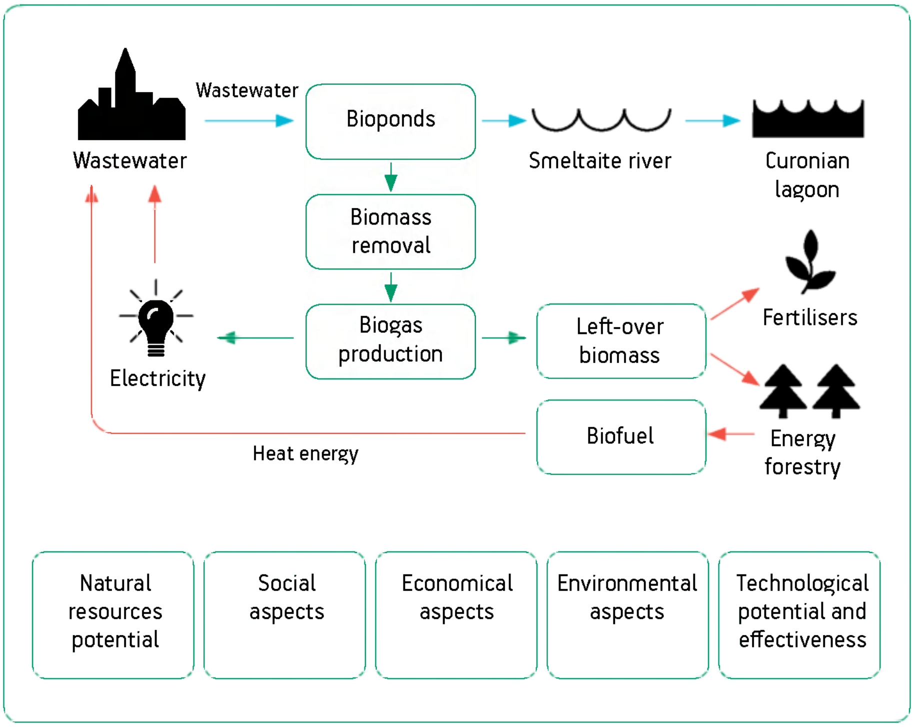
Biopond systems for wastewater treatment in Lithuania

Biopond are shallow artificially created water reservoirs that have potential to be used for biological wastewater treatment. They are cheap to build and useful when conventional wastewater treatment facilities are not available.

In Lithuania, where wastewaters from small settlements or recreational areas are commonly dropped directly into rivers without or with little treatment, this method is especially valuable. One such system of seven connected bioponds linked to the Smeltale river near Klaipeda is used to treat wastewater from ten industrial facilities who drop their waste into the river after primary treatment, domestic wastewater from surrounding houses and rainwater from local fields. Studies at these bioponds have shown that macrophytes and microalgae have reduced the concentrations of total nitrogen and phosphorus by 15 and 50 %, respectively.

A biopond with an area of 9300 m^2 has the capacity to serve about 4500 citizens from surrounding settlements at an initial cost of € 115,000. Using bioponds for water treatment was estimated to cost € 0,50/m^3 less than conventional methods (a savings of € 20,000 per year for a settlement of 4500 people). The biomass produced can then be used as a source of biofuel or biogas.

Figure 4: Nutrient and energy cycles in a sustainable wastewater treatment system.



PUTTING IT INTO PERSPECTIVE

RECYCLING CO_2 AND NUTRIENTS FROM WASTE STREAMS

Microalgae utilises about 2 kg of CO_2 per kg of algae produced and CO_2 emissions from energy production in Finland are 50 Mtn per year. If all this CO_2 could be used by microalgae, 25 Mtn of microalgae could be produced. Such production volume has an areal requirement of 4,000–20,000 km^2 or 1.2–6% of the total land area of Finland. Oil production from such vast area of microalgae cultivation could be 6 Mtn of oil per year, which is approximately equal to the current consumption of liquid transport fuels in Finland.

A similar analysis using phosphorus from municipal wastewater also highlights the importance of nutrient recycling during the microalgae cultivation process. Phosphorus load of untreated municipal wastewaters in Finland is approximately 4,500 tn per year. Assuming a microalgae phosphorus content of 0.5 %, this corresponds to an algae production potential of 0.9 Mtn per year and an areal requirement of 130-670 km^2. Projected oil production yields 0.2 Mtn of oil per year or roughly 4 % of the current consumption of liquid transport fuels in Finland. •

Competence Centres in the Baltic Sea Region

Worldwide, forerunners in applied microalgae research and commercial activities are found in the United States, Australia, Israel, Japan and several European countries like Spain, Italy, France, Germany and the Netherlands. All these countries have pilot sites for large-scale microalgae production and also commercial activities in production of high value compounds and technological solutions for cultivation.

Ecological and taxonomic microalgae research has a long tradition in the Baltic Sea. Several microalgal species have been isolated for research purposes and culture collections are maintained, typically by universities or research institutes. Nevertheless, applied microalgae studies aiming to commercialise the use of microalgae products and biomass or their cultivation methods or processing techniques have not been that common in the Baltic Sea Region, Germany being an exception. By now most Baltic Sea Region countries have dedicated funds for research on microalgae biofuels. Recently several research groups have been formed that also include small enterprises and large energy companies, covering a wide range of topics from basic algae lipid metabolism to dedicated technical solutions for cultivation, advancing the technology not only locally but also globally. Germany shows the strongest institutional capacity, but other Baltic countries such as Finland, Denmark and Sweden are getting more and more involved with several projects looking into the commercialisation of microalgae cultivation. Table 1 shows examples of some of the research institutions, projects and companies working on microalgae cultivation in the Baltic Sea Region.

Table 1: Examples of some of the research institutions, projects and companies working on microalgae cultivation in the Baltic Sea Region.

Research institutes / Projects / Companies	Focal area
AlgaeCenter consortium, Denmark	Set up of algae cultivation facilities at the Kattegatcentret at Grenaa Harbour, Denmark
Algae Innovation Center (Green Center), Denmark	Contribution to local and regional development and research on algae potential for different uses
Blue Bio project, financed by EU Interreg Programme (IVA Kattegat-Skagerrak)	Finding sustainable ways of exploiting the marine environment including microalgae
Chalmers University of Technology, Sweden	Production of bioethanol from microalgae biomass Microalgae harvesting
Finnish Environment Institute, Finland	Optimisation of microalgae lipid production, use of waste streams and flue gas in microalgae cultivation, life cycle assessments
IGV Gmbh, Germany	Algae cultivation and processing technology, photobioreactor design
Linnaeus University in Kalmar, Sweden	Use of microalgae for industrial CO_2 capture, recycling nutrients from wastewater and for bioenergy in the South Baltic Region
Neste Oil, Finland	Research on potential for using algae oil as a feedstock for producing renewable diesel
Nordic Algae Network (2012-13) financed by the Nordic Marine Innovation Programme	Evaluation of business opportunities in algae production and networking with commercial and research partners
RWE Power AG, Germany	Demonstration project on algae growth with flue gas
SimrisAlg, Sweden	Growing microalgae on CO_2-rich exhausts and wastewater
Swedish University of Agricultural Sciences in Umeå	Microalgae growth on municipal wastewater using flue gases from a combustion plant
Technical Research Centre of Finland	Design and validation of a new integrated concept of biowaste-to-energy based on algae and biogas production
Uppsala University, Sweden	Hydrogen production by microalgae
University of Turku, Finland	Hydrogen production by microalgae

Technology

To produce microalgae biomass for commercial applications a constant and controlled yield is required. This can be obtained through cultivation in ponds or photobioreactors. The methods used can depend on the species, the environmental constrains, the desired end products and the production volumes required.

Commercial cultivation of microalgae can take place in open/raceway ponds or in closed photobioreactors. In principle, microalgae concentration in cultivation systems is very high, up to 1–10 g of dry weight per litre. However, to obtain such densities fertilisers and CO_2 must be added to the culture media. From the harvesting point of view, this density is still very low (>99 % water) and several

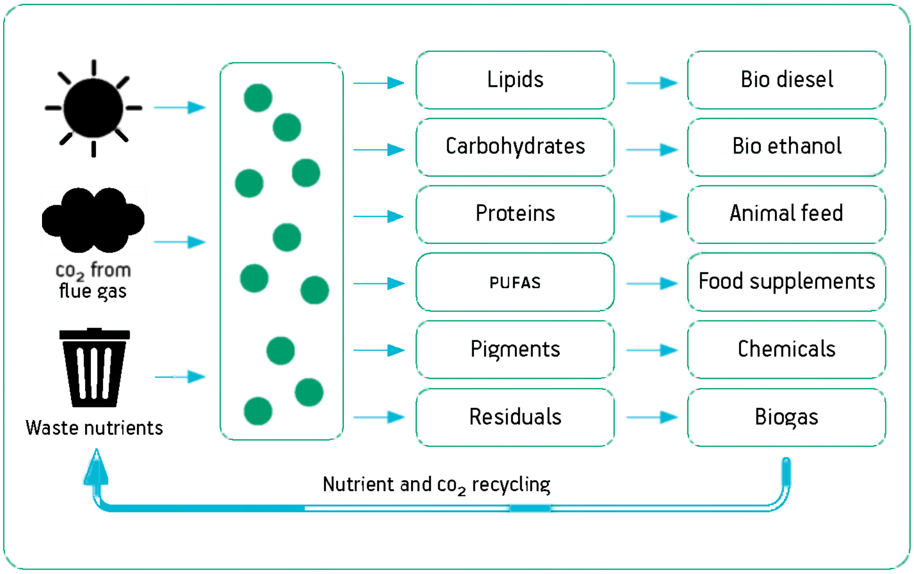
ADDITIONAL POINT

THE BIOREFINERY CONCEPT

As side products of biomass production, microalgae may also provide other commercially interesting compounds. The bio-refinery concept integrates the production of algae commodities and ecosystem services to maximise the economic and socioeconomic potential of algae cultivation (figure 5).

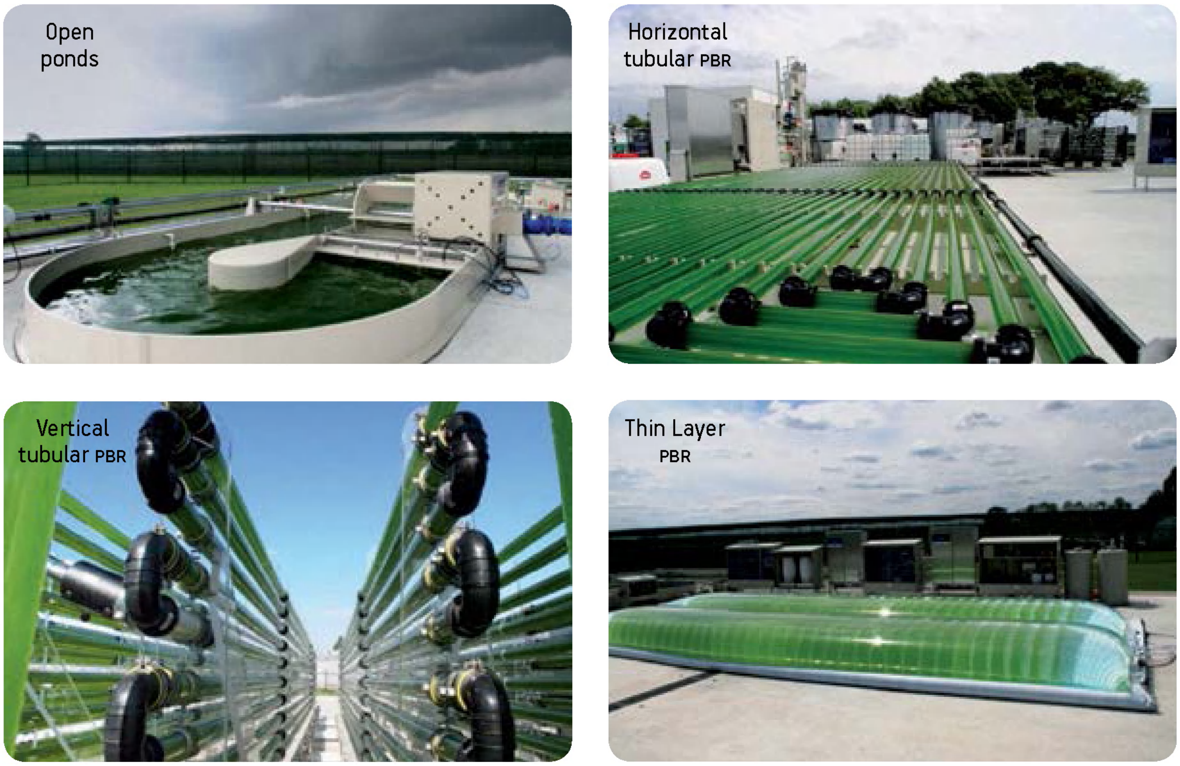
In biorefinery, various algae-based products are manufactured simultaneously. These may include various biofuel fractions (lipids for biodiesel, carbohydrates for bioethanol, residual biomass for biogas), feed (proteins) and commercial high value compounds (fatty acids, pigments). Additional economic benefit arises from ecosystem services provided, such as nutrient removal and CO_2 capture. Finally, the biorefinery concept may also include nutrient and water recycling.

Figure 5: Microalgae biorefinery combining production of low and high value compounds and ecosystem services.



The biorefinery scenario is also most likely for producing algae biofuels economically. These low value compounds are hard to produce economically unless other benefits are obtained with production of side products or with ecosystem services. For example, while the oil content of algae may reach 40–60 % of the dry weight, still considerable amount of biomass is left for other purposes.

Figure 6: Four different types of photobioreactors (pictures: AlgaePARK).



harvesting technologies are currently being tested and further developed.

Supplying light efficiently for cultures is also challenging. When exposed to direct sunlight, growth in the uppermost layers of the culture may be inhibited by too intense light, while due to high light attenuation further away from the light source, the cell growth rate is limited at low irradiances. In practice the optimal depth for cultivation is only 5–15 cm. Direct sunlight may also increase the temperature of the water too much and thus additional cooling may be required.

Another requirement is the constant mixing of the cultures to bring algae cells to the illuminated zones, evenly supply CO_2, remove oxygen produced and prevent temperature and nutrient gradients from developing. This is usually achieved with stirrers, pumps or air bubbles.

The simplest way to cultivate microalgae is in open ponds, which are much cheaper to build and operate than closed systems. To circulate water and keep cells in suspension oval shaped raceway ponds are typically mixed by paddlewheels. However, such mixing is often insufficient and part of the algae cells descend to the dark basin bottom and no longer grow until they are lifted up again. Other disadvantages are high contamination risks and water loss due to evaporation.

In closed photobioreactors algal cultivation can be monitored and controlled to a great extent, allowing savings in water, nutrient and energy use, Also, sunlight collection may be optimised in photobioreactors designed to maximise the surface-to-volume ratio of cultivation units. With this "light dilution" areal productivity can be increased. Photobioreactors are available in three different configurations: plate, tubular and thin layer.

In hybrid systems, photobioreactors feed carefully controlled algae biomass into larger open production systems, drawing benefits from both

ADDITIONAL POINT

CULTIVATING MICROALGAE AT SEA?

Most R&D efforts in the realm of microalgae cultivation focus on perfecting land-based systems. But given the space requirements for algae culturing on land and its limited availability in many countries which, on the other hand, may have large ocean areas, naturally the question arises: could microalgae be cultivated in ocean environments?

The concept poses enormous challenges. To get high microalgae yields the environment needs to be controlled to a significant extent in order to keep other species from taking over. Methods would need to be developed to control the microalgae growth media and separate it from the surrounding water to keep undesirable strains of algae from taking over the desired ones, which may not be particularly competitive. Furthermore, even in the Baltic Sea naturally available nutrients would be insufficient for substantial microalgae growth, which means additional fertilisation would be required. Thus, cultivating microalgae at sea would not counteract eutrophication in the Baltic Sea but rather bring about risks of increasing it. Therefore one cannot imagine the cultivation of microalgae with a simultaneous addition of nutrients as is done in some coastal areas in southeast Asia. Another major challenge involves harvesting, which would be particularly difficult in open ocean environments.

One offshore microalgae cultivation technology has nonetheless been developed by the US National Aeronautics and Space Administration (NASA).[9] The OMEGA (Offshore Membrane Enclosure for Growing Algae) system is targeted for use in nutrient rich wastewaters. It consists of large plastic bags with osmotic membranes where the algae are contained but the cleansed water is released into the surrounding ocean.

cultivation designs. Such systems are likely the most cost-efficient for production of low-value compounds.

The size of the cultivation area needed varies: some high value compounds may be produced commercially using rather small units, while commercial production of biofuels would require hundreds of hectares. To date, such large production facilities do not exist in the Baltic Sea Region.

Environmental Assessment

Environmental Impacts

Given the scope of the microalgae cultivation activity, it is important to consider its scale and full life cycle (e.g. from cultivation through to biofuel production) when assessing the possible impacts it may have on the environment. Microalgae cultivation is potentially an attractive environmental solution to supply biomass energy in the Baltic Sea Region. However, this depends on the feasibility of implementing efficient carbon sequestration and wastewater remediation technology to the cultivation process. While microalgae production has a high demand

Table 2: Overview of microalgae cultivation impact on environmental objectives and priorities.

Environmental Objective	**Environmental Priority**	**Microalgae**	**Comments**
Water quality	Bathing quality		
	Water transparency	🔵	By using waste streams
	Eutrophication	🔵	By using waste streams
	Biogeochemical cycles	🔹	By using waste streams
Habitat / Species protection	Food web dynamics	?	
	Biodiversity	?	
	Benthic habitats		
	Bird habitats		
	Fisheries		
	Marine mammals		
	Marine noise		
Coastal protection	Coastal morphology		
	Scenery	🔴	Depends on scale and location
Climate protection	CO_2 Emissions reduction	🔵🔴	Depends on Net Energy Ratio

🔵	strongly supportive
🔹	moderately supportive
🔴	strongly not supportive
🟠	moderately not supportive
○	neutral
?	gaps in information;
blank	not applicable

for CO_2 and fertiliser, when coupled with wastewater effluents and flue gas, it has a much lesser environmental impact with respect to energy consumption, water consumption and greenhouse gas emissions than selected terrestrial biofuel crops (corn, canola, and switchgrass).[10] It also significantly outperforms other crops in land use efficiency.

WATER QUALITY

When wastewater streams are used as the nutrient source for microalgae cultivation, the net effect on the water quality is a removal of excess nutrients locally and an improvement in the eutrophication status of the area. This will also have a positive impact on the biogeochemical cycling of elements in the water.

HABITATS / SPECIES PROTECTION

Changes to local aquatic food web dynamics and biodiversity may occur as a result of improved water quality from using waste streams. It is assumed that these would be favourable but it is not possible to make an assessment without further study.

SCENERY

The installation of large-scale algae cultivation units will have an unfavourable impact on the local scenery, the extent of which depends on the location. This will affect the recreational value of the area as well as the value of real estate.

CLIMATE PROTECTION

Microalgae cultivation for biofuel production is still at very early stages of development and is not projected to be an economically sustainable activity for another 10 to 15 years. Ultimately, large-scale production is envisaged. This naturally increases the dimension of environmental pressures that should be considered. The main concern is related to the amount of energy needed to produce biofuels from microalgae. The Net Energy Ratio (NER) is an important energy balance that describes the ratio of the total energy produced over the energy requirement for all operations. If NER < 1, then the process consumes more energy than is produced and is not economically feasible. However, favourable greenhouse gas emission reduction can still be realised compared to fossil fuel production with an unfavourable net energy balance.

Life Cycle Assessment

With an activity that has cultivation and production processes intrinsically linked, life cycle assessments are helpful in identifying important environmental impacts and issues and where obstacles may exist in the process. A number of studies have been carried out that explore the life cycle assessment of microalgae cultivation for biofuel production

Table 3: Overview of major obstacles in microalgae cultivation and suggested solutions.

Bottleneck	Main problem	Suggested solution
Cultivation technology	• Open pond: large area needed • Photobioreactor: high construction and operation costs, emissions from construction phase.	• Material choices • Combination of open pond and photobioreactor
Fertiliser need	Energy consumption of mineral fertiliser production	• Use of wastewater • Reject biomass use from anaerobic digestion
CO_2 need	Emissions and costs of the use of pure CO_2	CO_2 from flue gases
Harvesting and drying technologies	Energy use	Biofuel production technology choice
Lipid extraction in biodiesel production	Energy consumption	• Flue gas use as a heating source • Intensification of biodiesel production with use of crude glycerol (co-product during lipids to biodiesel conversion) through heterotrophic fermentation • Combined biodiesel and biogas production: biogas as energy source, digested reject as fertiliser • Biogas production alone: less energy needed for drying
Digester heating in biogas production	Energy consumption	
Digestion in biodiesel production	Energy consumption and nutrient recycling	Anaerobic digestion of oilcakes
Nitrogen and phosphorus remineralisation using anaerobic digestion	Release of nitrogen is toxic at high concentrations	• Microalgae co-digestion with nitrogen poor substrate. • Use species with high C:N ratio

and identify which production processes are the most energy demanding and hence where research efforts need to be invested to overcome these obstacles (table 3).

It is clear that many technical hurdles need to be overcome before microalgae cultivation for biofuel production can become an environmentally sustainable activity. It is difficult to compare individual studies directly as each study can have different boundaries circumscribing its system, e.g. some treat algae cultivation alone, some algae cultivation and biofuel/biogas production and some algae cultivation, biofuel/biogas production and end use of biofuel/biogas. Nevertheless, it is instructive to review the main findings of these studies as important life cycle phases and bottlenecks in the algae cultivation and biofuel production process are highlighted and in some cases solutions are proposed (table 3).

Socioeconomic Aspects

Economic Potential

Recognition of algae biofuels as an economically relevant alternative to fossil fuels has increased in the past years, especially in view of energy security and growing fossil fuel prices. As a sign of commercial potential, several oil companies have microalgae biofuels high in their research investment lists. New solutions to decrease algae production costs are continuously being sought.

According to the International Energy Agency (IEA), worldwide 100×10^9 L of liquid and gaseous biofuels were produced in 2011, contributing to approximately 3 % of total transport fuels. The demand of biofuels is expected to be 10-fold larger in 2050 than today according to the IEA.[11] The related economic potential is enormous, with roughly € 500 billion turnover per year. But to produce that amount of oil using microalgae would require roughly 1 million km^2 based on today's technology. Technological advances to improve productivity per area and decrease production costs are still required for competitiveness. In the future, with increasing prices of food, the large-scale production of animal feed or human food from microalgae may also become economically sound. As with fuel production, the size of these markets could potentially be enormous.

Microalgae Cultivation Costs

Current production costs of microalgae are generally considered to be in the range of € 5–20 per kg. For the time being, making realistic economic visualisations and thus identifying the most critical components in economic calculations is still very challenging as there exists no large-scale algae cultivation plants providing real costs for such calculations. Only preliminary economic calculations have been carried out. In addition to equipment and building costs, the supply of CO_2 and nutrients are important cost factors for large-scale algae cultures (figure 7). The major cost factors and possible solutions to decrease the costs of large-scale algae cultivation are presented in table 4.

In the Baltic Sea Region additional economic constraints arise as microalgae cultivation is not possible throughout the year. If culturing is used as

Figure 7: Major costs of algae production. Costs are estimated for a hypothetic 100 ha algae production plant in the Netherlands utilising raceway ponds. Total cost of production is estimated as € 5 per kg. For capital costs 10 % depreciation per year has been used. According to Norsker et al. 2011.[12]

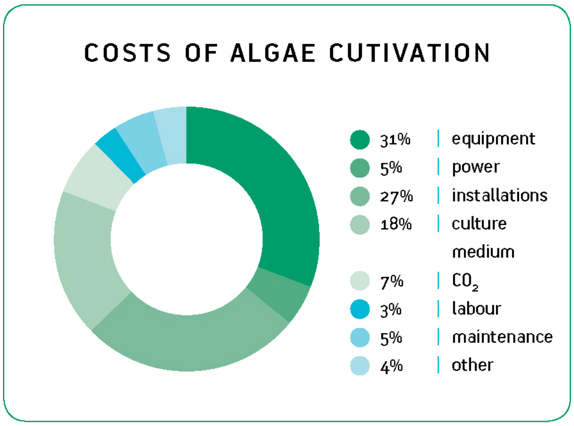


Table 4: Major cost categories in large-scale microalgae cultivation and possible ways of decreasing costs.

Cost Category	Means of Decreasing Costs
Labour	Automation of cultivation, scaling-up of processes, location of cultivation site
Cultivation equipment	New technical solutions for photobioreactors, finding robust algae strains
Mixing	Finding new energy saving methods for mixing
CO_2	Use of flue gases, recycling CO_2 (e.g. in algae biogas plants)
Fertilizer	Recycling of major nutrients, use of waste streams
Light	New innovations for distributing light in culture vessels
Water	Recycling of water
Photosynthesis efficiency	Increase of efficiency by strain selection or engineering
Content of end-product	Increase of efficiency by strain selection or engineering
Harvesting	New low-cost technology innovations
Extraction	New solutions to extract end products
Side products	Optimising algae production in biorefineries
Ecosystem services	Finding correct prices for nutrient and CO_2 recycling

a solution to treat waste streams, then additional costs come up as these wastes must be stored during the unproductive season or alternative cleaning methods must be operated in parallel.

Political Aspects

The European Renewable Energy Directive (2009/28/EC) sets as a target that by the year 2020 20 % of the total energy consumption and 10 % of the energy for transport used in the EU should come from renewable sources. In the directive, algae have been specifically mentioned as beneficial source of biofuels and R&D is encouraged. In addition, the Fuel Quality Directive (2009/30/EC) states that production of biofuels should be sustainable, preserving biodiverse and agricultural lands, though it does not directly mention microalgae cultivation as a one possibility. This shows interest in new renewable energy sources, including microalgae feedstocks, is increasing and related actions to finance R&D are being taken.

The European Commission has supported various research projects studying technical and biological aspects of large-scale microalgae cultivation for biofuels as well as projects supporting networking and capacity building. As an outstanding example, in 2010 the EC contributed € 21 million through the 7th Framework Programme towards the demonstration of microalgae production at an industrial scale (three industry-led projects were funded[13] though no partners from Baltic Sea Region were involved). In addition, several international and national programmes have been launched, many including financing from industry.

While no holistic European roadmap is available for algal biofuel technology some regional roadmaps and scenarios for large-scale microalgae production have been conducted, e.g. for Ireland.[14] Furthermore, the European Algae Biomass

Association[15] is an active stakeholder promoting microalgae biomass production and use. It represents several industrial and scientific partners and aims to raise attention on the potential of algae biomass in EU institutions and member States. Another association, European Biofuels Technology Platform, has initiated a taskforce focused on microalgae biofuels R&D.[16] These associations play an important role in bridging scientific community and industry and providing a joint position on international issues including legislation, specifications and standards.

Legal Aspects

As large-scale microalgae cultivation is still not operational in the Baltic Sea Region, there exists no legislation specific to this realm. Generally, the building of pilot-scale and full-scale algae cultivation units should follow national rules for permissions related to land and water use and wastewater treatment and requirements for environmental impact assessments.

In addition, there is always the concern that the cultivated microalgae will escape from cultivation units. In the case of microalgae, the escaped organism cannot be withdrawn from nature and thus organisms with possible adverse effects should not be cultivated. The international conventions, EU level regulations and national legislation have stated that necessary measures should be taken to prevent intentional or accidental introduction of alien species into marine environments. This applies to genetically modified organisms as well.

SWOT Analysis

STRENGTHS	WEAKNESSES
• Vast microalgae resources in the Baltic Sea • Provides several simultaneous products and services, including high-value compounds, nutrients removal, CO_2 utilisation and a potential source of biofuels • Potentially decreases eutrophication of natural waters by using nutrients from waste streams • Does not interfere with food production, compete for arable lands or use fresh water • Potentially mitigates climate change by utilising CO_2 from flue gas • Availability of strong scientific background in microalgae physiology in the Baltic Sea Region	• Production of microalgae low-value compounds not economically feasible in the nearest future • Economic calculations not yet reliable as no large-scale cultivation plant exists in the region • Scaling up highly productive systems at low cost may not be feasible • Huge demand for water for large scale cultivation (at the same scale as for plants) • Huge demand for land areas (not arable) for biofuel production • Although nutrients may be supplied from waste streams, these amounts do not support enough biofuel production on a level comparable to the current use of fossil fuels • Highly influenced by seasonal fluctuations of light availability and temperature, thus year round cultivation is not possible • Potential danger of invasive or genetically modified species release • Large-scale cultures are vulnerable to persistent biological contaminations and pathogens

OPPORTUNITIES	THREATS
Relatively large amount of CO_2 and nutrients in the region out of any commercial use and treated as negative externalities that society should cope with Growing demand for energy from alternative sources Growing prices for traditional energy carriers Plentiful technology companies willing to invest in research Strong governmental support for finding new innovative solutions for SMEs, especially in the energy sector Recognition of microalgae potential by several oil companies Networking with other research groups in Europe, China, India and the United States High level of multidisciplinary education in biology and energy sectors Facilities and knowhow for downstream processing EU support in the form of energy and climate change policies, EU Blue Growth initiative under Integrated Maritime Policy and structural funds Growing support for decentralised network economies	Unsustainable markets for microalgae side products Possible shortage of nutrients, CO_2 or water supply for scaled up microalgae cultivation Possible shortage of waste streams for large-scale production Investments channelled toward traditional energy sectors Lack of financial support due to the actual economic and financial crisis Lack of public support

Knowledge Gaps

Many things need to be considered before microalgae cultivation for biofuel production can be realised in an environmentally and economically sustainable way. Major knowledge gaps include:

- Availability of nutrients, CO_2 and water for various locations and their recyclability while upscaling the production.
- How to improve technical solutions in cultivation, harvesting and processing of microalgae biomass with a main emphasis on decreasing energy demand.
- Uncertainties in economic analyses, as full scale production units do not exist
- Integration with other commercial activities using the biorefinery concept should be solved and tested.
- Costs related to the use of waste streams should be evaluated in parallel to costs of traditional methods (e.g. using current municipal wastewater treatment plants)
- Sustainability and constrains of biomass productivity in large production units is unknown.
- How the prices of other energy forms and fertilisers affect the profitability of microalgae production.
- Environmental impacts not fully resolved as full-scale units not yet planned.

Conclusions

The global need for biofuels is increasing and microalgae may be part of the solution. Currently, however, the production is not yet economically feasible. It is obvious that several years of active biological research and biotechnological and engineering developments are needed to bring costs down to the level of fossil fuels and other biofuel alternatives. In this regard, the biorefinery concept offers hope in its ability to integrate the production of algae commodities and ecosystem services to maximise the socioeconomic potential of algae cultivation while offering the most likely scenario for producing algae biofuels economically.

The scales required for reasonable biofuel production (or for the treatment of substantial amounts of wastewater) are difficult to reach within the near future. Most likely, the way forward in large-scale microalgae cultivation will be tied to an increased production of microalgae-based high value compounds, including feed and food supplements. Pilot sites simulating large-scale cultivation conditions exist to some extent, including in the Baltic Sea Region, and many more such sites are to be expected. These provide a foundation for technical and biological innovations as well as opportunities to generate data for techno-economical modelling, all of which are required before a real scaling-up of microalgae cultivation can be imagined. During recent years research on microalgae biofuels has been significantly supported from a financial perspective. Whether the obtained results meet expectations will depend on several factors, including breakthroughs in other energy sectors. Although socioeconomic aspects, including spatial planning, and the economics and environmental issues of large-scale microalgae production have been studied, the findings remain uncertain since the whole production chain does not yet exist.

The opportunities in microalgae cultivation are global and the Baltic Sea Region will not likely be the first place where large-scale cultivation will take place. However, the Baltic Sea Region has a lot to offer for applied microalgae research. It has a long tradition in aquatic sciences and energy technology developments. The research in microalgae biofuels is of high quality, though it is also somewhat scattered and unfocused. Clearly coordinated actions are required.

A challenge for research funding in the Baltic Sea Region is how to gather all key players to generate nodes of excellence in microalgae biofuel research that are internationally outstanding. It is clear that this requires that companies from the energy sector, water treatment technology and microalgae cultivation technology form an alliance with research institutes. Finally, for further developments in applied microalgae research and industry the Baltic Sea Region needs involvement and support not only from individual nations but also from the regional programmes. These may promote networking, point to the need for new openings in research and funding, increase project visibility across borders and provide coordinated future scenarios and roadmaps for the Baltic Sea Region.

Recommendations

- The biorefinery concept and its supply of ecosystem services should be applied to improve the economics of large-scale cultivation
- Funding of high quality microalgae cultivation research and development should be encouraged
- Networking activities should be supported to improve capacity building and technology transfer between countries; the current activities in the Baltic Sea Region are partly overlapping, scattered and uncoordinated
- Support for public-private partnerships across borders in the Baltic Sea Region should be established
- Participation in research and development projects in developing countries should be encouraged, as well as active cooperation with the main global stakeholders
- Solutions for microalgae cultivation, including the use of waste streams and production of

co-products, are site specific. Therefore, generation of Baltic Sea Region-specific roadmaps, life cycle analyses and techno-economic models should be encouraged

- Local sources of nutrients and CO_2 for algae cultivation should be surveyed, including economic modelling of various alternatives for waste treatment. Based on the availability of resources, possible sites for microalgae cultivation should be highlighted
- Local microalgae species should be studied in more detail, with a well-coordinated plan. Special emphasis should be given to bloom forming species and species living in extreme conditions (ice, salt water ponds, waste water ponds)
- New microalgae strains should be isolated with enhanced properties concerning cultivation and yield of end products
- Innovation should be promoted in the development of new cultivation systems
- Improved means for recycling nutrients and water should be resolved
- Legal regulations of large-scale microalgae cultivation should be clarified
- Continue to monitor environmental impacts as the industry / production is scaled-up in the future

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Blue Biotechnology

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BIOTECHNOLOGY IS DEFINED as the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services (OECD). Marine or Blue Biotechnology encompasses the application of biotechnology tools on marine resources.

Marine organisms used for Blue Biotechnology can be both microorganisms, such as bacteria, fungi, and microalgae, or macroorganisms, such as macroalgae and mussels. They are directly used as biomass or as producers of valuable ingredients such as active biological compounds, pigments, antioxidants, vitamins, fatty acids, enzymes, polymers or other biomaterials.

High value marine products and technologies can have a wide range of applications in health, food, feed, cosmetics, aquaculture, agriculture, industrial processes, environmental remediation, environmental monitoring and research tools.

A variety of techniques are used in the field. Among them are the fermentation using bioreactors, microbiological and chemical techniques, as well as cell-, gene-, protein- and other molecule-based techniques.

Blue Biotechnology: The Future Is Now

Introduction

Over the last decades, interest in Marine Biotechnology has steadily increased as it has considerable potential to address global challenges related to population health and environmental sustainability and to serve as an engine for greener and smarter economies.

The application of biotechnology to marine resources has already yielded some notable and wide ranging advances in the fields of medicine, cosmetics, nutraceuticals (food products with benefits for human health), food production and environment and industrial applications, with related consumer needs only expected to rise in view of demographic change, increased disease incidence and growing environmental concerns.

By comparison with terrestrial resources, marine resources are largely untapped. It is thus expected that they can provide a new important resource for the identification of valuable ingredients. Indeed, with a yearly growth rate of 12 % patents associated to genes of marine organisms amounted to 4,900 by 2010,[1] indicating the high potential for an economic valorisation of marine products. The use of marine bioresources for biotechnological applications is no longer a futuristic vision but a growing source of business opportunities.

At the moment, the global Blue Biotechnology industry is still nascent and very much focused on research and development. It still has a limited economic performance and plays only a small part within the overall biotech market. But numerous studies[2] project major growth, huge demand and correspondingly large markets for marine biotechnology. The Marine Board of the European Science Foundation predicts a leadership role for research in Marine Biotechnology in Europe by 2012, with a market estimated at € 2.8 billion.[3]

Though technical competences are available in several of the Baltic Sea Region countries, Blue Biotechnology still plays a relatively small role in the economies and development plans of the region. However, the basic elements are there for the sector to be able to expand rapidly as long as the challenges existing in the transfer from research to commercial application will be coped, including financial support (see section on "Knowledge Gaps"). Also, the relevant actors in the region can stimulate the political will to promote and implement a joint and coherent development strategy.

Baltic Sea Organisms

A common feature of Baltic Sea organisms is the fact that their diversity is rather unexplored with respect to potential for biotechnological applications. Much of research has so far focused on organisms from other sea areas (esp. Pacific Ocean). Nevertheless also the Baltic Sea harbours a great diversity of marine organisms, which provide a great potential for exploitation.

As a brackish water body, one that is more saline than freshwater but less than seawater, the Baltic Sea comprises a diverse combination of freshwater and marine groups of microorganisms, with indigenous populations that have adapted to these unique conditions.[4] According to census estimates, the Baltic Sea hosts at least 6,065 species, including at least 1,700 phytoplankton, 442 phytobenthos, 1,199 zooplankton, 569 meiozoobenthos, 1,476 macroozoobenthos, 380 invertebrate parasites, about 200 fish, 3 seal and 83 bird species.[5]

It stands to reason that given the considerable species diversity of these waters, the potential for finding compounds of interest for application development is also significant. For example, it has been shown that some bacteria associated with macroorganisms from the Baltic Sea such as the alga *Saccharina latissima,* the sponge *Halichondria panicea* and several bryozoan species exhibit a great potential for the production of antimicrobial compounds.[6, 7, 8] A few other examples are known of Baltic Sea microbial strains that produce bioactive compounds, as shown in table 1.

As a matter of fact working with Baltic Sea organisms implies also other advantages. Expedition costs

Table 1: Baltic Sea microbial strains known to produce bioactive compounds.

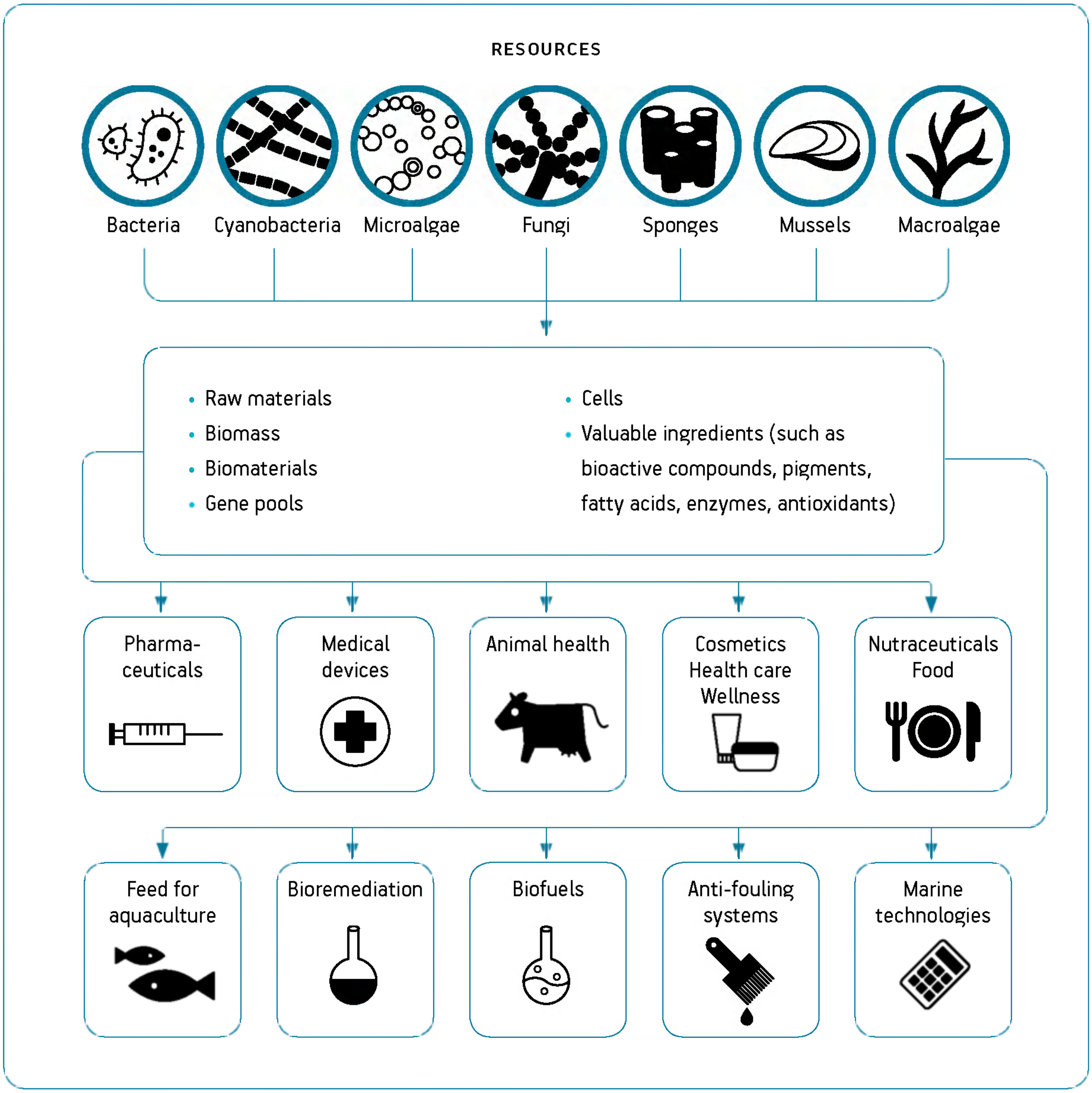
Compound	**Produced by**
Trophodithietic acid with antibacterial acitivity	*Roseobacter sp.*, a marine epiphytic bacterium[9]
Streptophenazines A-H with antibacterial activities	A strain of the bacterium *Streptomyces sp.* isolated from the sponge *Halichondria panicea*[10]
Mayamycin, a polyketide with inhibitory activity against a panel of tumor cell lines and antibiotic resistant human pathogens (patented)	A strain of the bacterium *Streptomyces sp.* isolated from the sponge *Halichondria panicea*[11, 12]
Tambjamine, a compound with the ability to kill nematodes	The bacterium *Pseudoalteromonas tunicata*[13]
Balticols A-F naphthalenone derivatives with antiviral activity against *Herpes simplex* virus type I	Fungal strain[14]
Compound Sch210972, an inhibitor of human leukocyte elastase playing a role in a severe lung disease	*Microplodia sp.*, a fungus obtained from the green alga *Enteromorpha sp.*[15]

to other sea areas are very high. Furthermore cultivation of indigenous organisms is much easier and legal as well as Intellectual Property questions are easier to be solved.

Applications

Blue Biotechnology has considerable potential to help address global challenges in population health, food security and industrial and environmental sustainability as well as protecting and preserving marine resources for future generations. The

Figure 1: Examples of the applications from various Baltic Sea microorganisms (e.g. bacteria, fungi, microalgae) and macroorganisms (e.g. sponges, mussels, macrooalgae) as sources of high-value products providing benefits for science and industry, for human health and environment as well as for growth and economy development of the Baltic Sea Region.



exploitation of marine micro – and macroorganisms is a promising tool to find solutions to these challenges through provision of products for the pharmaceutical industry, the medical field, human diet, animal feed, the cosmetics and wellness sectors, bioremediation and other purposes (Figure 1).

Pharmaceutical Industry

As the global incidence of infectious diseases, cancer, heart diseases, asthma, Alzheimer`s disease and diabetes continue to increase and simultaneously the number of antibiotic-resistant pathogens also grows, the need for development of new drugs has become ever more important, also with respect to an increase of the elderly population. Generally, natural products play an important role in the development of drugs, with 63 % of new drugs classified as naturally derived. Marine compounds show remarkably high hit rates in the screening for drugs.[16] More than 20,000 marine active compounds have been found until now with 80 % showing anticancer activity. Approved drugs are Cytosar-U®, Vira-A®, Prialt®, Halaven®, Lovaza®, Yondelis® and Adcetris®. A further successful example is the substance pseudopterosin, isolated from corals grown in mariculture in the Bahamas[17] which shows potential activity against psoriasis and neurodermatitis, inflammatory diseases, pain and rheumatic disease. The substance is in clinical trials phase II.

There is growing interest particularly in the exploitation of marine bacteria and fungi because microbial secondary metabolites, those organic compounds produced by the organism and involved in factors such as fecundity, survivability or defence, provide promising new structures for drug discovery[18, 19] and because a sustainable production of these bioactive compounds can be ensured by fermentation processes. Advances have been made in the identification of antimicrobial and antitumor compounds as sources for new anti-infective drugs and drugs for the treatment of cancer respectively.[20, 21, 22] Examples of bioactive compounds which were produced by microorganisms from Baltic are given in the section on "Baltic Sea Organisms". Table 2 gives an overview of the global marine pharmaceutical pipeline.

Table 2: The global clinical pipeline of marine pharmaceuticals as of July 2012.[23, 24]

Compound Name	Trademark	Marine Organism	Company or Institution	Disease Area
		Clinical Status: Approved		
Cytarabine, Ara-C	Cytosar-U®	Sponge	Bedford	Cancer
Vidarabine, Ara-A	Vira-A®	Sponge	No information available	Antiviral
Ziconotide	Prialt®	Cone snail	Azurpharma	Pain
Eribulin Mesylate (E7389)	Halaven®	Sponge	Eisai Inc.	Cancer
Omega-3-acid ethyl esters	Lovaza®	Fish	GlaxoSmithKline	Hypertriglyceridemia
Trabectedin (ET-743)	Yondelis®	Tunicate	PharmaMar	Cancer
Brentuximab vedotin (SGN-35)	Adcetris®	Mollusk	Seattle Genetics	Cancer

Compound Name	Trademark	Marine Organism	Company or Institution	Disease Area
Clinical Status: Phase III				
Plitidepsin	Aplidin®	Tunicate	PharmaMar	Cancer
Clinical Status: Phase II				
DMXBA (GTS-21)	–	Worm	University of Colorado Health Sciences Centre	Cognition Schizophrenia
Plinabulin (NPI 2358)	–	Fungus	Nereus Pharmaceuticals	Cancer
PM00104	Zalypsis®	Mollusk	PharmaMar	Cancer
Elisidepsin	Irvalec®	Mollusc	PharmaMar	Cancer
PM01183	–	Tunicate	PharmaMar	Cancer
CDX-011	–	Mollusk	Celldex Therapeutics	Cancer
Tasidotin, Synthadotin (ILX-651)*	–	Bacterium	Genzyme corporation	Cancer
Clinical Status: Phase I				
Marizomib (Salinosporamide A, NPI-0052)	–	Bacterium	Nereus Pharmaceuticals	Cancer
PM060184	–	Sponge	PharmaMar	Cancer
SGN-75	–	Mollusk	Seattle Genetics	Cancer
ASG-5ME	–	Mollusk	Seattle Genetics	Cancer

* – Phase II has been completed

Cosmetics, Health Care and Wellness Products

In cosmetics, surfactants („surface active agents“) are compounds that lower the surface tension of a liquid or that between a liquid and a solid and are thus used as cleansers, detergents, solubilisers, foaming agents and emulsifiers. Surfactants can be found in almost all kinds of products based on powders, liquids, lotions, creams, gels and sprays.

In tune with current ecological concerns, chemical surfactants are giving way to biologically produced surfactants such as phospholipids, lipopeptides and glycolipids originating from marine organisms (Table 3). In contrast to conventional surfactants, bio-surfactants are completely biodegradable and hence environment-friendly. Furthermore, they are less toxic and more stable over a wide range of temperatures and pH. Alone in 2006, 255 patents related to bio-emulsifiers and bio-surfactants were issued (33 % in the petroleum industry, 15 % in the cosmetics industry, 12 % in medicine and 11 % in bioremediation).[1] The exploitation of these patents could enhance the output of marine products containing surface active compounds.

Several companies in Europe already successfully market cosmetics containing compounds of marine origin. Examples are Esteé Lauder with Resilience®, a product containing the pseudopterosin compound is used as an additive preventing irritation caused by exposure to the sun or chemicals,[25] Aqua Bio Technology ASA (Norway), with Aquabeautine XL®, a skin care product con-

Table 3: Examples of surfactant-producing bacteria and fungi used for cosmetic applications.

Microorganisms	Surfactant	Effect	Product
Candida bombicola	Sophorolipids	Moisturizing, foaming, emulsifying	Deodorants, body washes, and acne treatments
Pseudomonas aeruginosa	Rhamnolipids	Anti-microbial, emulsifying	Anti-wrinkle and anti-aging cosmetics
Candida antarctica	Mannosylerythritol lipids	Emulsifying, dispersing	Smoothing and anti-wrinkle products

taining proteases and proteins from salmon and Daniel Jouvance (France) and Thalgo Cosmetic (France, Germany), with micro – and macroalgae based cosmetics.

Enzymes for Industrial Processes

In the frame of the Europe 2020 Strategy the European Commission calls for "Innovating for Sustainable Growth: A Bioeconomy for Europe" which addresses the sustainable use of renewable resources for industrial purposes in 2012.[26] It is also already a trend and one which is expected continue growing, to replace more and more chemical products and processes with biologically-based ones, as they are more environmentally friendly and thus have higher acceptance among consumers. For example, cold-adapted enzymes, those synthesised by organisms that thrive in cold environments, are now being used to improve industrial processes as they allow for the reduction of the water temperature and thus the energy required for a process. Currently, 40 % of the total sale of enzymes applies to proteases, lipases, amylases and cellulases used as additives in detergents in order to reduce the temperature required for washing.[27]

Another useful benefit of cold-adapted enzymes is that they can be inactivated with mild heat. This is

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Raw materials or extracts from Baltic Sea macroalgae species have already been used for cosmetic and health care products. Species such as *Agarum cribosum* or those of the *Laminaria* genus have been used to manufacture anti-aging formulas due to their hydrating properties. The red microalgae *Porphyridium sp.* and *P. aerugineum* have natural active shield released to the proximate surroundings, creating a thick protective layer around the cell. This was incorporated in the hydrogel *Alguard*™, manufactured by Frutarom to provide quick beauty skin protection.

In Estonia, curative mud originating in Haapsalu Bay, Käina Bay and the Mullutu coastal lake are increasingly being used for wellness, thalasso therapy and care in medical spas (see also "Reed Harvesting" chapter). A number of cosmetic and health care product manufacturing companies in the Baltic Sea Region already market products based on components produced by marine organisms or containing marine ingredients.

Table 4: Examples of cosmetic and health care manufacturing companies in the Baltic Sea working with marine organisms.

Company	**Product**
ORTO (Estonia)	Cosmetic products from sea mud from Haapsalu
GoodKaarma (Estonia)	Organic soaps made from sea mud from Haapsalu
MADARA (Latvia)	Macroalgae based cosmetics
oceanBASIS (Germany)	Oceanwell and o'well med cosmetic series made from brown macroalga *Saccharina latissima*, Ocean Collagen Pro Age containing collagen from a marine organism
AQUAZOSTA MB (Germany)	MAREZOSTIN® cosmetic/thallasso-wellness products derived from eelgrass *Zostera marina*
Heitland & Petre International GmbH (Germany)	Maresome® derived from cyanobacteria *Anabaena sp.* with activity against skin bacterial infections caused by multiresistant *Staphylococcus aureus* (MRSA)
Ocean Pharma GmbH (Germany)	CuraMar® algae based products for nail care
Inwater Biotec GmbH (Germany)	Algae based cosmetics
La Mer (Germany)	Skin care products using mud from the Wadden Sea
Meereskosmetik Macon (Germany)	Cosmetics from marine extracts
Dalton Kosmetik (Germany)	Skin care products based on sturgeon extracts
Biomaris (Germany)	Skin care products with active ingredients from sea minerals and seaweed

particularly useful in those industrial processes in which the contact of the enzyme with the substrates to be transformed should be limited in time so as to prevent excessive or deleterious action. An example is that of cellulases used in the textile industry for stonewashing, i.e. the process of producing a worn appearance on textiles, in which the excessive action of the enzymes could lead to the loss of mechanical resistance of the cotton fibres.

Cold-adapted enzymes are also used in the food processing industry, with meat tenderising with proteases as the best example. As an example, the food manufacture Unilever has developed a low fat ice cream containing an anti-freeze protein from the Arctic ocean pout, cold-water fish.[28] Other applications include the removal of lactose in milk with β-galactosidases and the improvement of the volume and crumb quality in bread with xylanases.[29] Some additional examples of enzymes, which can be useful for industrial processes, are listed in Table 5. In the near future, it is expected that other applications such as enhancing extraction yield, enhancing fruit juice taste by pectinases and developing new tastes and flavours with lipases will also be implemented. Research and /or application of enzymes from marine organisms is not only performed e.g. by ArcticZymes (Norway) but also by companies located at the BSR, such as Enzymicals AG (Germany), BRAIN (Germany) or DANISCO (Denmark).

Table 5: Examples of enzyme use for industrial processes.

Enzyme	Synthesizing Microbe	Property	Industrial Use	References
Protease	Symbiont in shipworm	Alkaline pH	Cleansing additive	Greene, 1996[30]
	Bacillus mojavensis	2 detergent stable serine proteases	Detergent	Haddar, 2009[31]
Lipase	*Penicillicum oxalicum, Aspergillus flavus*	Cold-adapted	Detergent, paper production	David, 1935[32]
Phospholipase C	Marine streptomycete	Optimum at pH 8 and 45°C; only hydrolysis of phosphatidylcholin		
Alginate lyase	Algae, marine invertebrates, microbes		Novel alginate polymers	Wong, 2000;[33] Xiao, 2006;[34] Alkawash, 2006;[35] Gacesa, 1988,[36] Gacesa, 1992[37]
Agarases	Agarolytic microbes	Softening or liquefying of agar	Processes for production of beverages, bread and low-calorie foods	Rasmussen, 2007;[38] John, 1981;[39] Oren, 2004;[40] Yaphe, 1972;[41]; Aoki, 1990;[42] Leon, 1992;[43] Hosoda, 2003;[44] Sugano, 1993[45]
Carrageenase	Red seaweeds, marine molluscs, marine bacteria		Coagulant, adhesive, stabiliser, emulsifier	Sarwar, 1987;[46] Roberts, 2007[47]
Amylase	Bacteria, fungi, sponges		Bread-making process	Gupta, 2003[48]
Cellulose and hemicellulose hydrolase	Bacteria, fungi		Bio-textile auxiliaries, cotton and linen processing, bio-fertiliser processing, seaweed degradation	Klemm, 2005;[49] Tong, 1980;[50] Doi, 2008[51]
Fibrinolytic enzymes	Bacteria	High stability towards various surfactants and oxidizing agents	Laundry detergent, thrombolytic agent	Mahajan, 2012[52]

Food and Feed Products

Numerous food supplements can be traced back to compounds of marine origin. Microalgae, for example, are commonly used as a food supplement, with some of the most valuable products being polyunsaturated fatty acids (omega-3 fatty acids) and antioxidants (e.g. β-carotenoid).[53]

From the aquaculture perspective, there is a great challenge in providing new cheaper feed products, as the feed constitutes about 50 % of the cost drivers (for fish). New healthy feed products are also necessary to prevent diseases and to enhance the quality of the cultivated organisms. Animal proteins should be replaced by plant products, such as those from algal origin. Cultured microalgae are already used as a feed additive in mollusc and shrimp aquaculture[54] as well as in feed for poultry, pigs and some pets.[55] The microalgae pigment astaxanthin is an especially valuable feed additive in salmon farming, giving the pink colour of the fish meat.

Biomaterials

Though this is still a very new field, over the past decade the medical, pharmaceutical and biotechnological industries have directed increasing attention towards biomaterials such as biopolymers of marine origin. Microbial biopolymers are polysaccharides, chitins or collagens, which have numerous applications ranging from bioplastics (such as polyhydroxyalkanoate, also know as PHA, which is synthesised by various marine bacteria) to pharmaceutical and

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Research on microalgae high value compounds from the Baltic Sea Region for use as food and feed supplements has been quite limited, though several Lithuanian studies have looked into the use of *Spirulina* and *Chlorella* microalgae as dietary supplements for humans and animals.[56,57,58,59]

Production is thus far mostly small scale but several companies throughout the region have successfully marketed various (mostly algae-based) compounds for use in the food and feed industries.

Table 6: Examples of Baltic Sea Region companies and institutions investigating or producing food and feed additives from marine organisms

Products	**Company/Institution**
Spila Spirulina as food additive and Spilamix as feed additive, from *Spirulina platensis*	SPILA UAB (Lithuania)
Nutraceuticals and feed additives	BlueBio Tech GmbH (Germany)
Nutraceuticals	Biovico (Poland)
AstaREAL® astaxanthin from microalgae Haematococcus pluvialis	Bioreal AB (Sweden)
Algae food, chitofood (using chitin from crustacean shells)	ttz Bremerhaven (Germany)
Omega-3 fatty acids	Finnish Environment Institute – SYKE (Finland)

Unsaturated fatty acids, especially docosahexaenoic acid (DHA) as a food supplement	MareNutrica (Germany)
Food supplements such as omega-3 from microalgae	SimrisAlg (Sweden)
Alternatives for fish feed and fish meal using in vitro fish cell cultures	Fraunhofer Research Institution for Marine Biotechnology EMB (Germany)
Colourants for food and feed	Sea & Sun Technologies GmbH
Food supplements such as polyunsaturated fatty acids from microalgae and processing of innovative products	IGV GmbH (Germany)
Products with *Chlorella* as food supplement (tablets, powder, bread, pasta, sweets)	Roquette Klötze GmbH & Co KG (Germany)

medical polymers for sealing wounds, bio-adhesives, dental biomaterials, tissue regeneration and 3D tissue culture scaffolds.[60] As an example products of the company HemCon Medical Technologies (USA), such as HemCom® Bandages PRO, are based on chitosan.

In comparison to conventional polymers, biopolymers have the advantage of being biodegradable, less toxic and based on renewable resources. Marine biopolymers may have a major future market potential but are currently still in development stage.

Bioremediation of Marine Ecosystems

This relatively novel application involves the use of oil-degrading bacteria to improve water quality. Oil is a complex mixture of hundreds of different compounds generated from dead biomass over millions of years. In parallel, certain microorganisms, some of which are a common part of the marine microbial community in the Baltic Sea, have developed special enzyme systems to be able to use some of the oil components as substrate. Research is therefore going into the identification of microorganisms that might be able to mitigate the negative effects of accidental oil contamination from ship accidents or leakage of oil platforms.

So far, no microbes are known that are able to degrade the whole spectrum of oil components. To estimate the amount of active oil-degrading species as well as the cocktails of enzymes they produce for these purposes will require both molecular-ecological and metagenomic approaches. But the starting point is an encouraging one, as investigation of the microbial diversity in Baltic Sea sediments has already revealed the presence of microbial strains possibly involved in degradation of the pollutant phenantrene.[61]

Anti-fouling Systems

Surfaces in the marine environment are rapidly colonised by microorganisms such as bacteria, a process which is then followed by colonisation by macroorganisms such as barnacles. This usually poses a problem for ships when a biofilm grows on the bottom, resulting in reduced cruising speed, high fuel consumption and thus increased CO_2 emissions.[62] Anti-fouling coatings are thus used containing chemical substances that prevent the formation of biofilms. Because these coatings often have toxic effects, legal regulations such as the International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS Convention) – adopted in 2001 by the International Maritime Organisation – are in place to promote restriction or even ban of toxic compounds such as tributyltin (TBT) used for anti-fouling.

Marine bio-based coating with anti-fouling and anti-corrosive properties may offer new solutions to the shipping industry. This promising new research field is investigating marine bacteria for their potential to produce compounds exhibiting anti-fouling activities. Since marine organisms have developed defence strategies against competitors and antagonists, they are involved in processes preventing fouling as it was shown for bacterial biofilms being active against barnacle attachment in the Baltic Sea.[63] Recent studies in Danish coastal waters have found marine bacteria showing anti-adhesive effects on a biofilm-producing *Pseudoalteromonas* sp. bacterium as well as on zoospores of the green alga *Ulva australis*.[64] Further research is still needed to identify the bioactive compound(s), conduct an Environmental Risk Assessment and develop a process for manufacturing an anti-fouling system based on this compound. The development of anti-fouling systems is carried out e.g. by the University of Gothenborg (Sweden) and the company LimnoMar.

Biofuels

The aspect of using biomass from marine organisms for the production of biofuels is covered in chapter 3 “Macrogalgae Harvesting and Cultivation” and chapter 6 “Microalgae Cultivation”.

Technology

Technological pre-conditions: from finding towards scale-up

Two phases can be distinguished in the search for valuable ingredients from marine micro – and macroorganisms, which require different kinds of technical equipment:

In the 1st Phase focus lies on “finding” organisms with interesting characteristics for a wide spectrum of possible applications (figure 2 shows the steps involved in drug discovery): In this phase it is essential to build and conserve microbial culture collections that keep the strains available for further investigation and production. In order to get the desired compounds from the cultivation experiments, extraction methods are performed using, for example, organic solvents. For the purification of compounds and the elucidation of their structures several techniques are employed, among them high-performance liquid chromatography (HPLC), mass spectrometry (MS), nuclear magnetic resonance (NMR), gas chromatography (GC) and fast centrifugal partition chromatography (FCPC®). Known compounds produced by the organisms in cultivation experiments must be quickly identified to avoid ‘rediscovering’ of already known compounds. The marine natural products in substance libraries have to be maintained in high purity and high amounts in order to provide enough material for high throughput screening procedures with the aim to apply as much as possible test systems. For example, the search for new drug candidates requires a broad range of screening panels using bioassays relevant for human health; i.e. assays for determining the inhibitory activity of compounds against antibiotic resistant human pathogens, against tumour cell lines or enzymes playing a key role in diabetes or Alzheimer´s.

After establishment of the process at laboratory scale the 2nd Phase starts, in which it is necessary to prove reproducibility and to scale-up the production to ensure the amounts of biomass and substances required at all stages of product development to enable commercial production according to the industrial requirements. Scale-up involves the use of fermenters (10–3,000 L or even higher) for the cultivation of the bacteria, fungi or microalgae strains that will be producing the compounds (figure 3). In case of the cultivation of macroorganisms the availability of appropriate systems for mariculture or aquaculture is essential for a high yield in biomass. Subsequently the so called downstream processing is carried out comprising technologies which are necessary to separate and to purify the desired ingredient from the biomass e.g. by mechanical, analytical and preparative separation

Figure 2: "Finding Phase": Summary of steps involved in the exploration of marine natural products from microorganisms for drug discovery.[65] The path of isolation of microbes from the marine habitat in order to gain bioactive compounds for further drug development is illustrated. Once bacteria and fungi have been brought into pure culture, straightforward procedures are available to cultivate them in larger volumes, to chemically analyse the natural products and identify the compounds, as well as to optimise the production by strain selection and elaboration of the optimal physicochemical conditions for production. This includes design and development of the fermentation process and selection of strains from a larger panel of similar strains that produce the desired compound as well as strain improvement by random or directed genetic manipulation.

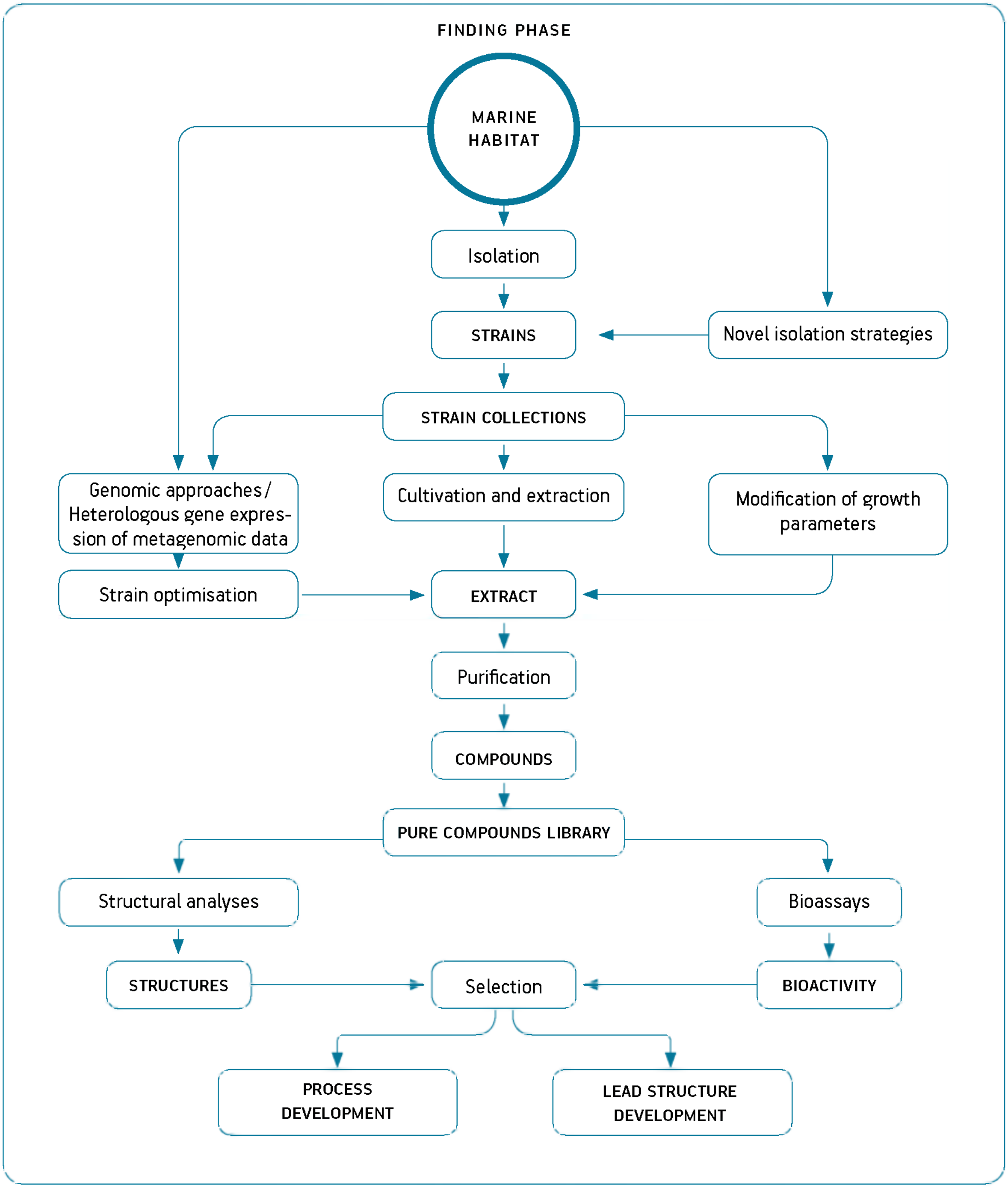


Figure 3: Fermenter at GEOMAR | Helmholtz Centre for Ocean Research Kiel.

technologies, such as centrifugation, the use of absorbers, and/or chromatography. Dependent on the intended purpose of the purified ingredient several steps follow to develop the market product, e.g. to evaluate the sufficient concentration to be used, the suitable formulation or the proper carrier-material for specific technological applications.

GENOMIC TECHNIQUES

Despite the success of the traditional culture-based, bioassay-guided strategies used to discover new natural products, genetic analyses have revealed that these approaches provide access to only a small fraction of the biosynthetic capacity encoded in microbial genomes. This is because more than 99% of all bacteria are to date still not cultivable under laboratory conditions. Also, the majority of biosynthetic pathways are only expressed scarcely or not at all under laboratory conditions and the products of these pathways have been overlooked.[66] This means that a microorganism may have the potential to produce a promising drug candidate but the conditions for inducing the production of this compound are unknown. Therefore, several genetic techniques are performed with the aim of accessing these compounds.

One approach is the analysis of the full genome sequence of a cultivated strain or a single cell obtained directly from the environment. This allows the detection of genes coding for metabolites that have the potential to exhibit promising properties. Several genomics-inspired strategies have been applied in unveiling new metabolites.[67] Among these strategies is the scanning of genomes to predict chemical structures from genes and the transfer of genetic material coding for compounds of interest from marine microorganisms into easily grown "producer strains" such as *Streptomyces* sp. bacterial strains.[68, 69]

There is strong evidence that the marine pharmaceutical pipeline as well as the portfolio of new enzymes will be up-scaled in the near future with products from uncultivable marine bacteria. New metagenomic techniques, those focused on studying the genetic material recovered directly from environmental samples, will be increasingly applied with the aim of accessing this large gene pool containing information for valuable products. As an example Hardemann & Sjoling (2007)[70] detected a novel lipase from Baltic Sea sediment sample by a metagenomic approach. This enzyme might be used for industrial application because of its activity at low temperature.

Further technologies, such as the aquatic cell technology, which is based e.g. on fish or algae cells, respectively, for the production of valuable ingredients for feed and other applications or the development of biosensors by using e.g. genetic information or toxins from marine organisms also contribute to the sustainable use of marine biotechnology.

Laboratories in the Baltic Sea Region

In the Baltic Sea Region, the landscape of public institutions and private companies focusing on exploration and exploitation of marine organisms for biotechnology is relatively scattered and no systematic mapping has been conducted to assess the distribution of players and their roles, interests or technical expertise.

Overall the majority of activity appears to be focused in northern Germany as well as Denmark, but recently also individual institutions / researchers in Finland, Poland and Sweden have started to be active in EU financed projects such as MAREX, MARINE FUNGI and MicroB3.

Generally technical facilities in form of highly equipped laboratories exist in almost all countries throughout the Baltic Sea, because there is an increasing interest in biotechnology. A fact becoming evident e.g. by the initiatives of the Latvian Biotechnology Association (LBA), the feasibility study for an Estonian Biotechnical Programme[71] and from reports about biotechnology in Lithuania.[72] Many institutions have so far mainly worked on marine biodiversity research or in biotechnology at general level. But their equipment could be used with hardly any further investment for the exploitation of marine organisms as well. The Latvian JSC "Biotehniskais Centr" could for instance provide fermentation capacities for the cultivation also for marine microorganisms producing valuable ingredients for biotechnological products.

However, no network or strategy is in place to promote their awareness of each other at the level of the whole region – which would be a pre-condition to enable the sharing of their (expensive) capabilities and the knowledge generated in the field Blue Biotechnology.

Furthermore – whereas capacities seem to be sufficient for the 1st "Findings" Phase – there seems to be a lack in capacities for scale-up and downstream processing, i.e. process development. In this phase not only large scale facilities (e.g. 3000 l fermenters) are required, but also sophisticated organisational /quality assurance systems in order to comply to legal regulations (i.e. documentation) (see section on "Legal Aspects").

Competence Centres in the Baltic Sea Region

It goes without saying that Blue Biotechnology does not only require natural ingredients and sophisticated technology, but also highly specialised experts in such diverse disciplines like microbiology, zoology, genetics, chemistry and pharmacy. Whereas in early years, most research and development in the field of Marine Biotechnology was conducted in academic institutions from one disciplines, today's landscape of natural product development is much more diversified and tremendous amounts of investments are related to these activities.

Specialised Marine Biotechnology research centres have now been established all over the world, where all the necessary disciplines and expertise are bundled together to contribute to integrated research and developments. Several examples of these specialised research centres exist in Europe, including the Marine Biodiscovery Centre in England or the Department of Biotechnology at SINTEF Materials and Chemistry in Norway. Additionally, networks including research institutions and companies with a clear marine biotechnological core business have been established. One of these is the Marine Biotech Cluster in Tromsø, Norway.

In the Baltic Sea Region research centres with special expertise in different fields of Blue Biotechnology are located in almost all countries. Examples are given in table 7.

Table 7: Examples of research centres and EU 7th Framework Programme projects with a research focus on various fields in Marine Biotechnology.

Research Centres	Activities relevant to Marine Biotechnology
Northern Germany	
University Greifswald and associated Institute of Marine Biotechnology e.V IMaB	Natural products, marine enzymes, functional genomics, metabolomics, discovery of new drugs, biotransformation, nanoparticles and active compounds
Kieler Wirkstoff-Zentrum at GEOMAR (The Kiel Center for Marine Natural Products at GEOMAR)	Bioactive compounds from microbes, pure compound library, bioassays, genomics, process development, scale-up, discovery of new drugs and enzymes, research on the biological function of bioactive compounds and their producers at marine habitats; network "Blue Biotechnology"; Lead Partner to FP7 MARINE FUNGI
University of Bremen	Marine genomics, lead partner to FP7 MicroB3
Fraunhofer Research Institution for Marine Biotechnology EMB	Development of new technologies, processes and instruments in the fields of biological water quality control, aquaculture technology, stem cell isolation and utilisation (e.g. fish cells) and others
Institute for Marine Resources GmbH (IMARE)	Biosensors, mariculture, technical applications of marine structures / nanomaterials
Denmark	
Danish Technical University (DTU)	Marine bioactive compounds, Partner to FP7 PharmSea
University of Copenhagen KU-Science	Marine bioactive compounds, food and feed with marine-derived ingredients
Latvia	
Latvian Institute for Aquatic Ecology	Environmental monitoring
Finland	
Helsinki University	Lead Partner to FP7 Project "MAREX"
VTT Technical Research Centre of Finland	Partner to FP7 Project "MARINE FUNGI"
Lithuania	
Klaipeda University Coastal Research and Planning Institute (CORPI)	Marine bioactive compounds from microalgae
Estonia	
Estonian Marine Institute of University Tartu	Environmental monitoring
Competence Center of Food and Fermentation Technologies (Tallinn)	Food containing marine-derived ingredients
Sweden	
Finish Environment Insitute (SYKE)	Fatty acids from marine microalgae for diverse uses
University of Gothenborg (with MareLife, Norway)	INTERREG IVA project BlueBio (Blue Biotechnology for sustainable innovations in the region Öresund-Kattegat-Skagerrak)

Research Centres	Activities relevant to Marine Biotechnology
Poland	
University of Gdansk	Partner to FP7 MAREX, bioactive compounds from marine microalgae, marine genetics, environmental monitoring
Institute of Oceanology of the Polish Academy of Science	Marine bioactive compounds, marine genetics, environmental monitoring

Environmental Assessment

The full scope of environmental impacts that the Blue Biotechnology field may have on the marine environment is still difficult to assess. This is because much of the work is still in an experimental stage but also because generally exploration is supported by highly competitive commercial companies, so most of the research and development efforts are not published in the literature. Nevertheless, research on and application of marine biotechnology is not expected to have negative impacts on the environment. In contrast, marine biotechnology will include strong positive impacts.[73] Among them might be the reduction of environmental damages on marine environments and the improvement of the climate. Some preliminary issues can be elaborated on (Table 8).

Habitat and Species Protection

The disturbance of the biological environment that occurs with the extraction of the species and capture of non-target species is considered negligible. In one litre of water from the Baltic Sea or on the surface of a single leaf of algae there are millions of bacteria and thousands of fungi and microalgae each with the potential to produce valuable ingredients for human and environmental health. Therefore, only tiny amounts of the original sample (such as a piece of sponge, coral or sediment) are needed. Several laboratory enrichment and cultivation techniques are then used to make the microorganisms available for further research. In the case of macroorganisms (e.g. macroalgae, mussels) it is possible to cultivate them using aquaculture, whereby environmental damage by harvest from the habitat is avoided. In this case, environmental impacts associated with the cultivation of macroalgae or mussels should be considered (see “Macroalgae Harvesting and Cultivation” and “Mussel Cultivation” chapters).

The unknown consequences to habitats and species through the release of bioengineered compounds or bacteria into the marine environment are potentially of greater importance. The need for environmental monitoring and surveillance has been identified as a growing factor over coming decades.[73] Very little is known at this point about the impact of using bioengineered compounds or bacteria in the marine environment and further research and monitoring of these types of applications is required. It is essential that marine biosource compounds and bacteria be developed that can be safely used in the marine environment.

Water Quality

One important application of Blue Biotechnology is the development of marine bio-sourced compounds that can safely replace toxic anti-fouling or anti-corrosive agents currently used on ships and submarine installations, thereby improving water quality. In addition, there is the application of bioengineered bacteria for bioremediation purposes following pollution events. Furthermore, the development of monitoring and detection systems based on compounds such as microalgal or bacterial toxins produced by marine organisms and which are harmful to humans as allergens or contaminants in seafood could help prevent diseases caused by these toxins.[74, 75]

Table 8: Overview of Blue Biotechnology's impact on environmental objectives and priorities.

Environmental Objective	**Environmental Priority**	**Impact of Blue Biotechnology**
Water quality	Bathing quality	🔵 ?
	Water transparency	🔵 ?
	Eutrophication	🔵 ?
	Biogeochemical cycles	🔴 ?
Habitat / Species protection	Food web dynamics	○ ?
	Biodiversity	◍ ?
	Benthic habitats	◍ ?
	Bird habitats	◍ ?
	Fisheries	◍ ?
	Marine mammals	◍ ?
	Marine noise	
Coastal protection	Coastal morphology	
	Scenery	
Climate protection	CO_2 Emissions reduction	🔵

🔵	strongly supportive
◍	moderately supportive
🔴	strongly not supportive
🟠	moderately not supportive
○	neutral
?	gaps in information
blank	not applicable

Large masses of plastic and plastic debris have been released into the environment, and thereby have entered the world´s ocean.[76] The use of alternatives, such as biodegradable products might contribute to resolve this long-standing problem, because degradation could be performed by enzymes produced by bacteria.[77]

Climate Protection

The main cause of the current global warming trend is the greenhouse effect. Microbial processes have a central role in the global fluxes of the key biogenic greenhouse gases (carbon dioxide, methane and nitrous oxide). With molecular-genetical approaches different groups of microorganisms should be identified which can dissimilate the organic part of the Baltic Sea water to carbon dioxide and therefore may enhance the greenhouse effect. If we understand the mechanisms of bacterial CO2-production it might be possible to influence this negative impact. Recently, bioengineered bacteria have been shown to improve the efficiency of the fermentation process in producing ethanol from macroalgae, potentially overcoming one of the major barriers to using macroalgae for biofuel production[78] and supplying a renewable energy source. A pilot facility is under way in Chile, though the environmental impacts of the technology have not yet been assessed. The use of enzymes derived from marine organisms to enhance industrial processes can also bring about improvements in energy consumption.

Socioeconomic Aspects

Encouraging Forecasts

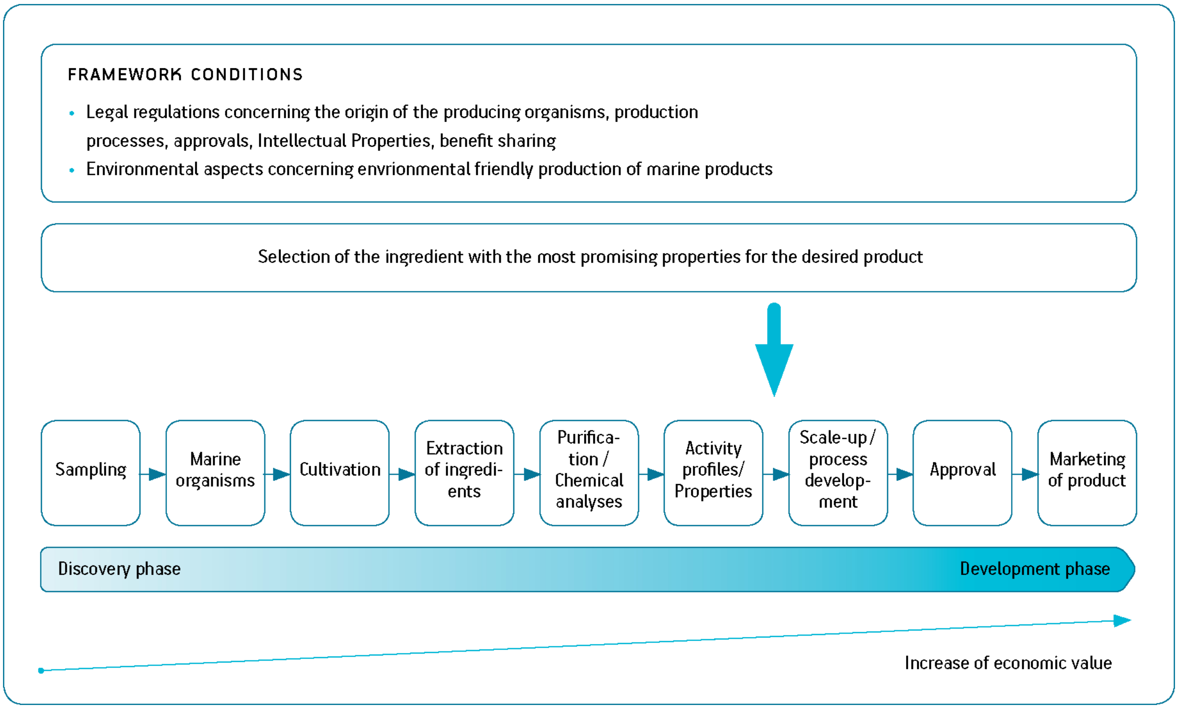
The global biotechnology revenues came to $ 84.5 billion in 2010 by analysis of 622 companies.[79] While Blue Biotechnology represents only a nascent and relatively small part of this market, given the vast untapped potential the marine biotech sector holds promising growth prospects for the future. The global market for marine biotechnology is forecast to reach $ 4.1 billion by 2015. The market for marine bioactive substances is forecast to register the fastest growth rate of more than 4 % during the period 2009–2015 and the marine biomaterials market was projected to reach $ 1.7 billion by 2012.[80]

Europe constitutes one of the largest markets for the marine biotechnology industry with about 27 % of the demand.[2] The Marine Board of the European Science Foundation estimates that Europe's segment of the Blue Biotechnology market amounts to € 2.8 billion ($ 3.5 billion) by with a future annual growth potential of 12 % assuming a strong cooperation of industry and science.[3] Furthermore, Baltic Sea countries contributed almost half of the European demand for marine biotechnology in 2011.[2]

This expected market growth is driven not only by the rise in interest from medical, pharmaceutical, aquaculture, nutraceutical and industrial sectors, with ever widening applications in many end-use areas (pull-effect). It is also "pushed" by the rapid increase in the inventory of marine natural products and genes of commercial interest derived from bioprospecting efforts. As a consequence, today an ever greater number of small companies exist with the specific focus of marketing marine compounds.

In terms of end-use, the healthcare industry constitutes the largest and fastest growing segment for marine biotechnology. The global market for marine-derived pharmaceuticals was valued at nearly $ 4.8

Figure 4: High-added value chain of the exploitation of marine organisms from the habitat to commercialisation of biotechnological product.



billion in 2011, $ 5.3 billion in 2012 and is projected to be worth nearly $ 8.6 billion by 2016, a compound annual growth rate of 12.5 % between 2011 and 2016.[81]

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Blue Biotechnology: A Real Business

As the first important commercial company in the world with a clear emphasis on development of anti-cancer drugs from marine natural products, the Spanish company PharmaMar was founded in 1986. It has several marine drug candidates in the clinical trial pipeline. Yondelis® was derived from a tunicate and was the first product from PharmaMar in clinical use against special forms of cancer.[82] It is applied as drug for the treatment of soft tissue sarcomas, is supplied by Zeltia and had gross sales of € 72.2 million in 2010, a 70.3 % increase on 2009.[83]

Challenges and Cost Factors

The overarching challenge to marine biotechnology concerns the appropriation of marine resources, which are distributed within vast and complex ecosystems, while protecting and preserving marine resources for future generations.[84] Among key issues for Blue Biotechnology are the supply of organisms producing e.g. bioactive compounds, enzymes or fatty acids for biotechnological applications, the use of bioassays suitable for the desired field of application, the sustainable production of these ingredients, proper storage methods, sufficient technologies for scale-up and downstream processing as well as the development and the approval of the respective market product (figure 4). Downstream processing may cause up to 80 % of the production costs.[85] Table 9 displays the phases involved in the discovery and the development stages for marine derived products as well as the facilities required.

In the pharmaceutical field, one important bottleneck in the development of drugs is the great financial effort needed to carry out pre-clinical and clinical studies, required for ensuring the efficiency and safety of new drugs (approval). Furthermore compliance with legal regulations, which vary depending on the final application of the compound (for drugs, medical devices, cosmetics or food additives) have to be considered (see section on “Legal Aspects”). The consideration of these regulations before being able to bring a marine product to market is cost-intensive.

Table 9: Cost factors playing an important role in Blue Biotechnology.

Stage	Phase of biodiscovery / development	Procedures / methods	Laboratories / Equipment	Staff	Main cost factors (examples)
Discovery	Sampling	Collecting marine samples	Ships, remotely operated vehicles	Scientists, technicians	Financing the cruises
	Supply of new producer micro-organisms or of metagenomic data sets , maintenance of culture collections	(i) microbiological methods (ii) genetic methods	(i) Laminar flows, autoclaves, incubation chambers, storage capacities for strain collection (-80°C, liquid nitrogen) (ii) S1 laboratories / thermalcyclers, sequencers, analytical software	(i) Microbiologists, biologists, technicians (ii) Geneticists, bioinformaticians, technicians	Staff salaries, purchase of equipment and laboratory materials
	Development of new cultivation – and/or genetic – based methods to stimulate production of known producer strains	Microbiological and/or genetic methods	See above + fermenters	See above	See above
	Extraction, structure elucidation, purification and storage of the valuable ingredients (e.g. as pure compound library)	Extraction procedures, chemical analyses	Laboratories following guidelines for chemical work, rotary evaporators, fraction collectors, HPLC, FCPC, MS, GC, NMR	Chemists, technicians	See above
	Screening panels with bioassays according to human, environmental and industrial needs	Cell-based test systems, enzymatic test systems	L2 laboratories, cell-culture laboratories, microplate readers for high-throughput	Microbiologists, cell biologists, pharmacists, agronomists, technicians	See above
Development	Sustainable supply of the valuable ingredients in sufficient amounts used for the marine products	(i) robust process development using fermentation procedures (ii) chemical synthesis (iii) genetic methods	(i) fermenters (250 L, 3,000 L and more) (ii) HPLC, FCPC, MS, GC, NMR (iii) S1 laboratories	Microbiologists, chemists, geneticists, engineers, technicians	See above
	Marine product development	Optimisation of the properties of the valuable ingredients according to product requirements, manufacturing using (bio) chemical methods, formulations	Equipment for chemical syntheses, software for structure-activity relationships	Chemists, medicinal chemists, pharmacists, biologists, technicians	See above

Stage	**Phase of biodiscovery / development**	**Procedures / methods**	**Laboratories / Equipment**	**Staff**	**Main cost factors (examples)**
Development	Ensuring Intellectual Property	Agreements and contracts with respect to benefit-sharing and joint ownership, patent applications	Offices	Patent lawyers, legal scholars	Costs for application and maintenance of the patents
	Approval of the marine product	Considering EU and national directives for the desired application	Laboratories according to Good Manufacturing Practice guidelines, national guidelines and EU directives	Staff with specific expertise in the desired application (e.g. medics, pharmacists, biologists, chemists, nutritionists)	Fulfil the requirements of the approval procedures (e.g. in case of drugs: clinical phases I, II, and III)
	Commercialisation of the marine product	Evaluation of market potential, development of marketing strategy	Marketing via internet, fairs, conferences, etc.	Business and marketing experts	Marketing costs including staff salaries, add campaigns, travel costs and product samples

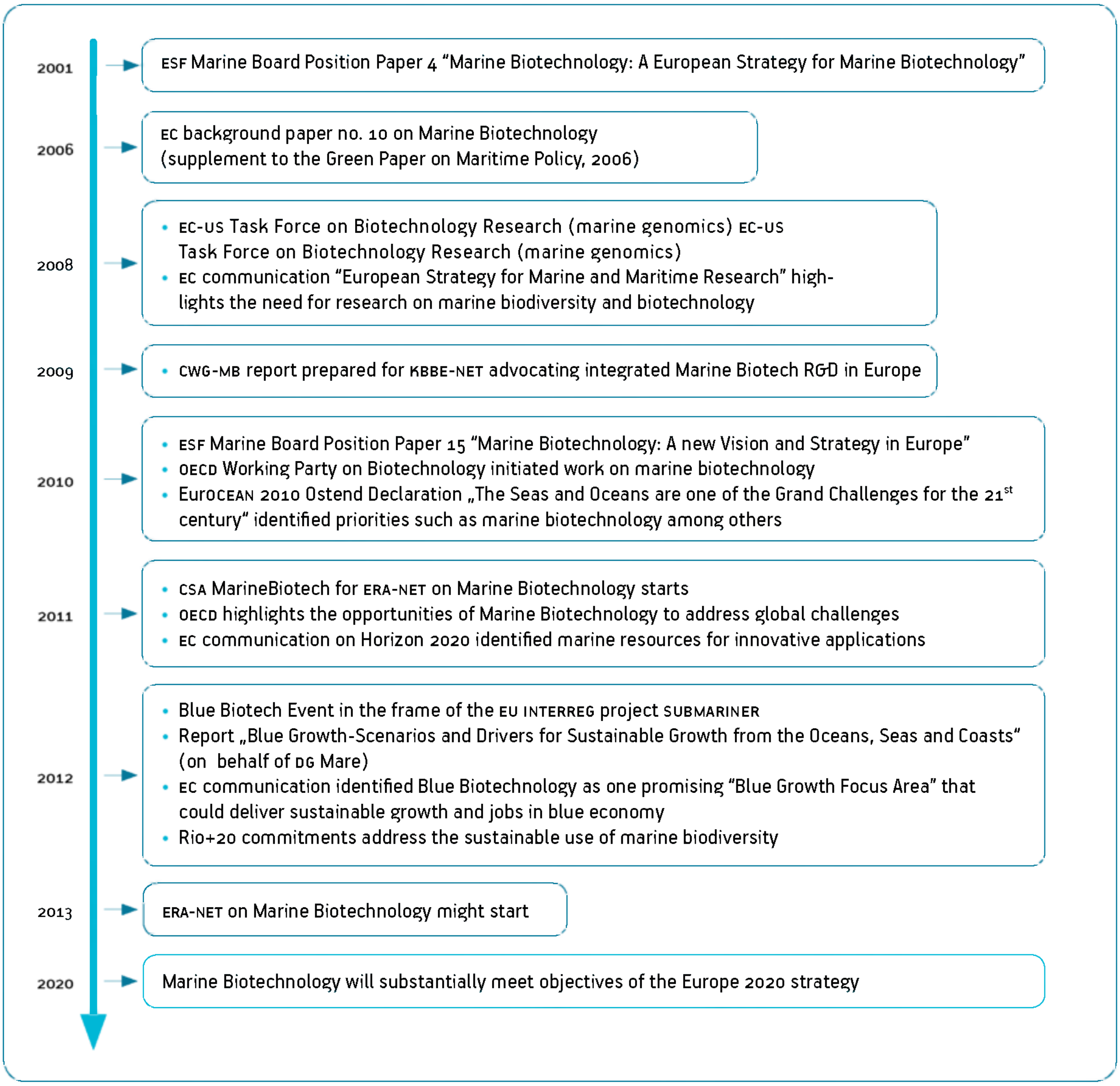
Political Strategies

European Context

In Europe, the potential value of marine resources for Blue Biotechnology is only just beginning to be recognised at the political level (Figure 5). Already back in 2001, the European Science Foundation’s (ESF) Marine Board Position Paper 4 “Marine Biotechnology – A European Strategy for Marine Biotechnology” had recognised the underexploited benefits of marine biotechnology in Europe and called for a European initiative to mobilise scattered human capital and refocus dispersed infrastructure. By 2009, the European Commission’s Knowledge Based Bio-Economy Network (KBBE-NET) advocated for integrated marine biotechnology R&D in Europe and made the first attempt to map national research priorities in European countries. In 2010, ESF´s Marine Board updated their Position Paper “Marine Biotechnology: A New Vision and Strategy for Europe”,[3] calling for a collaborative industry-academia approach to provide strategic assessment, identify priorities, analyse the socioeconomic context and provide policy recommendations. In 2011, the Internal Co-ordination Group for Biotechnology (ICGB) of the OECD stated that Blue Biotechnology has a considerable potential to address global challenges in population health, food security, industry and environmental sustainability as well as protecting and preserving marine resources for future generations.[84]

Despite these calls for strategic direction, to this day the EU still lacks a coherent marine biotechnology research and technology transfer policy. Instead, individual European countries support, to varying degrees, national and regional marine biotechnology initiatives and programmes based

Figure 5: Most important documents and activities from science and policy regarding marine biotechnology on the European level. (ESF = European Science Foundation, EC = European Commission, CWG-MB = Collaborative Working Group on Marine Biotechnology, R&D = Research and Development, OECD = Organisation for Economic Co-operation and Development, CSA MarineBiotech = Coordination and Support Action "MarineBiotech", ERA-NET = European Research Area Network, DG Mare = Directorate-General for Maritime Affairs and Fisheries, KBBE-NET = Knowledge Based Bio-Economy Network).



2001

ESF Marine Board Position Paper 4 "Marine Biotechnology: A European Strategy for Marine Biotechnology"

2006

EC background paper no. 10 on Marine Biotechnology
(supplement to the Green Paper on Maritime Policy, 2006)

2008

- EC-US Task Force on Biotechnology Research (marine genomics) EC-US Task Force on Biotechnology Research (marine genomics)
- EC communication "European Strategy for Marine and Maritime Research" highlights the need for research on marine biodiversity and biotechnology

2009

- CWG-MB report prepared for KBBE-NET advocating integrated Marine Biotech R&D in Europe

2010

- ESF Marine Board Position Paper 15 "Marine Biotechnology: A new Vision and Strategy in Europe"
- OECD Working Party on Biotechnology initiated work on marine biotechnology
- EurOCEAN 2010 Ostend Declaration „The Seas and Oceans are one of the Grand Challenges for the 21st century" identified priorities such as marine biotechnology among others

2011

- CSA MarineBiotech for ERA-NET on Marine Biotechnology starts
- OECD highlights the opportunities of Marine Biotechnology to address global challenges
- EC communication on Horizon 2020 identified marine resources for innovative applications

2012

- Blue Biotech Event in the frame of the EU INTERREG project SUBMARINER
- Report „Blue Growth-Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts" (on behalf of DG Mare)
- EC communication identified Blue Biotechnology as one promising "Blue Growth Focus Area" that could deliver sustainable growth and jobs in blue economy
- Rio+20 commitments address the sustainable use of marine biodiversity

2013

ERA-NET on Marine Biotechnology might start

2020

Marine Biotechnology will substantially meet objectives of the Europe 2020 strategy

on their own needs and priorities, resulting in a fragmented effort.

The EU currently provides about € 36 million to fund Blue Biotechnology initiatives through its 7th Research Framework Programme (2007–2013). Within this framework several projects focussing on the exploration of marine organisms have recently been selected, i.e. MaCumBa, PharmSea, BlueGenics and SeaBioTech and are expected to start by the turn of 2012 / 2013.[86]

Even though this shows the growing interest of the EU in this field, the € 32 million committed still only represent a small fraction of the overall € 1.9 billion spent on food, agriculture and biotechnology initiatives. Also the rather short term cycles of project based funding do not correspond with the long-term processes required in the field of Blue Biotechnology. Rather than being able to pursue a specific research field over a longer time span and thus being able to build up the necessary expertise – researchers and research institutes often have to shift emphasis according to the given funding opportunities rather than the other way round.

Further strategic support is expected through the Blue Growth initiative recently launched by the European Commission's DG Mare, which will focus among other topics, on the use of marine resources in the pharmaceutical and cosmetic industries. Recently the communication of the European Commisssion "Blue Growth – opportunities for marine and maritime sustainable growth" emphasised that Blue Biotechnology is one of few Blue Growth Focus Areas with the potential for research and development to deliver technology improvements and innovation.[87] European support for Blue Biotechnology can also be found in the ERA (European Research Area)-NET in marine biotechnology preparation action by the CSA MarineBiotech project, which is currently scoping the content and shape of a transnational funding activity and beginning the work of securing commitment to the provision of funds.

Baltic Sea Region Context

In the Baltic Sea, Germany and Denmark, have recognised the potential of the Blue Biotechnology sector and its various applications.

GERMANY

In Germany, Schleswig-Holstein has been a pioneer in the Blue Biotechnology field, beginning back in 2003 with its "Current status and future perspectives of marine bioactive compounds" report provided by the former Technology Foundation of Schleswig-Holstein.[88] The state's government then started the initiative "Zukunft Meer – Sea our future" in 2004, which includes Blue Biotechnology as one of the promising topics. This led e.g. to the financial support of the Fraunhofer Research Institution for Marine Biotechnology EMB and to the foundation of the Kieler Wirkstoff-Zentrum (KiWiZ) at GEOMAR (Kiel Center for Marine Natural Products at GEOMAR), a research centre specifically focused on research and development of compounds from marine microorganisms for use in various applications.

DENMARK

In Denmark, the Ministry of Food, Agriculture and Fisheries has made efforts to set a strategic direction for the nation's Blue Biotechnology industry. Keeping in mind the specific competence of the various companies (9) and research institutes (>15) present in Denmark in this field as well as the potential economic benefits to be achieved, it suggested six priority areas of marine biotechnology[89]: increased exploitation of marine biomass, new farming operations, healthy diet, discovery of new compounds, materials and biological activities, extraction of valuable biochemical components and biofilms.

Elsewhere, Blue Biotechnology initiatives remain disjointed efforts or projects mainly driven by individual researchers and /or institutions. No cohesive strategic plan is available for the development of this sector in the Baltic Sea Region as a whole.

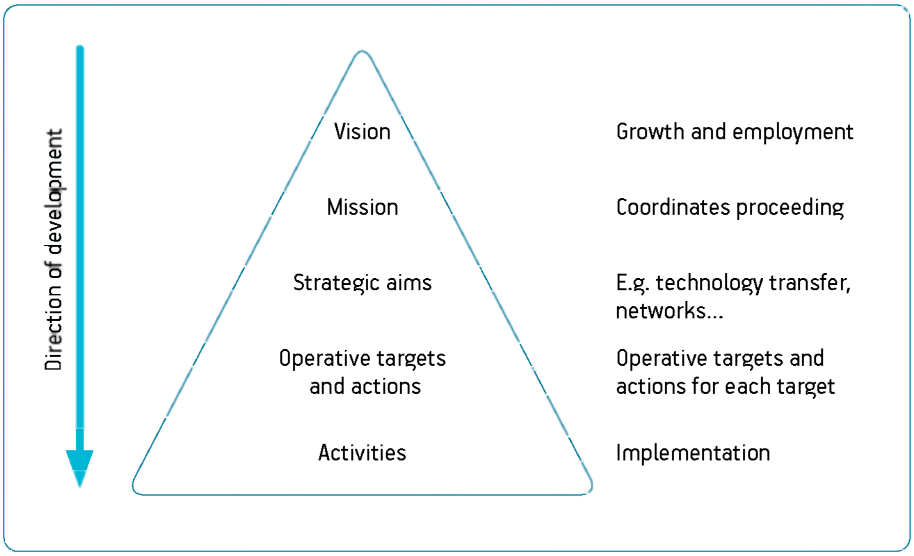
However, the basic elements on which to build such a strategy would already be in place. As shown, technologies necessary for bioprospecting of Baltic organisms are already established in some regions or countries, providing a good basis for technology transfer to other Baltic Sea countries. Furthermore local and international networks in the Baltic Sea Region that cover related fields such as life sciences or biotechnology (e.g. Life Science Nord, ScanBalt) already provide a good basis for promoting the Blue Biotechnology sector.

REGIONAL CASES

A Model for the Region?

The “Masterplan Marine Biotechnology Schleswig-Holstein – a regional development strategy” will be implemented in 2013 and will provide a path to the long-term strategic development of marine biotechnology in the state. The promising potential of marine biotechnology will be explored economically in a sustainable manner, through systematic knowledge and technology transfer and should lead to the generation of growth and employment in Schleswig-Holstein. This could serve as model for other countries and the Baltic Sea Region as a whole.

Figure 6: Structure of the Masterplan.



Legal Aspects

The process from research and development to marketing of a product from marine resources involves many single steps, which are strongly linked to ensure the protection of the environment, the Intellectual Property protection of all collaborators and the safety for the consumers using the marine product. Therefore it is necessary to consider various laws, guidelines and agreements. Some of the most important ones are given in following section to give an impression about the complexity of regulations.

Environmental and Species Protection

The Convention of Biological Diversity (CBD) has four objectives the conservation of biological diversity, the sustainable use of the components of biological diversity and the fair and equitable sharing of benefits arising out of the utilisation of genetic resources. The Microorganisms Sustainable Use and Access Regulation International Code of Conduct (MOSAICC) is a voluntary code of conduct drafted by worldwide partners from both commercial and not-for-profit sectors which serves as a tool to support the implementation of the CBD at the microbial level in accordance with relevant rules of international and national laws.

It is worth noting that European legislation is also in place concerning environmental liability. The directive 2008/56/EC of the European Parliament and of the Council address at establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). This pillar of the of the European maritime policy stated "…Member states shall take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at last." Further regulations focus on the prevention and remedying of environmental damage (2004/35/CE) as well as the deliberate release into the environment of genetically modified organisms, in case this is desired, as for instance for the degradation of pollutants (2001/18/EC).

Intellectual Property

The application for a patent is necessary to safeguard the exploitation rights of a new marine product with commercial potential. The European Patent Convention (EPC) provides an autonomous legal system for the granting of European patents via a single, harmonised procedure before the European Patent Office (EPO). The EPC is linked and interfaces with the national patent laws of the EPO member states. Generally, the European patent is subject to the same conditions as a national patent granted by that country. All Baltic countries have developed and adopted patent protection laws into their national legislation.

Concerning the ownership of patents arising from multinational collaborative projects, European Intellectual Property Rights regulations ensure that jointly generated Intellectual Property is also jointly owned (following share assignments previously agreed by the joint owners) and that rules are set for protection, use, licensing, cost and profit sharing and territorial division of patent protection and exploitation markets.

Safety and Good Manufacturing Practices

Safety regulations concerning the approval for the specific application of a marine product have to be taken into account before it can put in the open market. European directive 2004/10/EC provides principles of good laboratory practice that must be applied to the non-clinical safety testing of items contained in pharmaceutical products, pesticide products, cosmetic products, veterinary drugs, food and feed additives and industrial chemicals.

In the case of drugs for humans and veterinary drugs the approval of the responsible higher federal authority or the permission of the European Commission is necessary (according to the guidelines of Good Manufacturing Practice and regulations such as 2003/94/EC, 91/412/EEC, 726/2004/EC, 1901/2006/EC, 1768/92/EEC, 2001/20/EC, 2001/83/EC, 726/2004/EC and 1394/2007/EC or 90/385/EEC, 93/68/EEC, 93/42/EEC, 2001/104/EC and 98/79/EC for the marketing of medical devices).

In the case of food additives, under European legislation, these must be authorised before they can be used in foods. The authorisation is granted following safety assessments carried out by the European Food Safety Authority, which provides independent scientific review. EU legislation consists of a framework directive covering additives in general (89/107/EEC) as well as directives for colouring (94/36/EC), sweeteners (94/35/EC), other food additives (95/2/EC), food enzymes (1332/2008/EC) and other directives pertaining to approved purity criteria.

Suppliers wishing to place cosmetic products on the EU market must comply with the EU cosmetics directive 76/768/EEC. Among the main requirements are a safety assessment of the finished cosmetic product and the availability of the product information file. The directives 2001/36/EC and 98/8/EC concern the placing of plant protection products and biocidal products, respectively, on the market.

SWOT Analysis

STRENGTHS

- Enormous potential for growth, with many Baltic micro – and macroorganisms already used for market products or showing great potential for high-value applications
- Technologies necessary for bioprospecting of Baltic organisms are already established in some regions or countries, providing a good basis for technology transfer to other Baltic Sea countries
- Existing local and international networks in the Baltic Sea Region that cover related fields such as life sciences or biotechnology (e.g. Life Science Nord, ScanBalt) provide a good basis for promoting the Blue Biotechnology sector
- Successful commercial case studies in the Baltic Sea Region are already available
- Internationally well-known scientists are already working in specific fields of Blue Biotechnology in single regions of the Baltic Sea. These scientists could be promotors for technology and knowledge transfer for enhancing activities in Blue Biotechnology in their own but also in other Baltic countries.

WEAKNESSES

- Low awareness in most Baltic Sea Region countries about the economic and scientific potential of Blue biotechnology
- Skills shortage, especially in the cross-cutting disciplines necessary for development of high-value products from Baltic Sea organisms
- Limited number of financially strong companies in the Baltic Sea Region
- Challenging framework for the foundation of new companies (legal regulations, financial support, high taxes)
- Low technology transfer, low networking activities and low collaborative activities in the Baltic Sea Region concerning Blue Biotechnology
- Low readiness or aptness of the companies to invest in R&D in some Baltic Sea Region countries
- Limited readiness of venture capitalists to invest in young start-up's
- Limited skills and finances in sales and marketing within the companies that have already developed products of Baltic Sea origin
- Limited knowledge on the scale of environmental impacts, in particular arising from the release of bioengineered compounds into the marine environment.

OPPORTUNITIES

- Universities have high activities in R&D with a lot of innovative, application-oriented projects, highly encouraged scientists and modern, well equipped facilities so that innovative products can constantly be expected in the near future
- Companies are constantly searching for new and innovative ideas to fulfil customer needs
- Growing interest in marine biotechnology as a potential source for greener and smarter economies
- Growing market of the cosmetics industry

THREATS

- Lack of a coherent EU marine biotechnology research and technology transfer policy
- Lack of policies supporting biotechnology in some Baltic Sea Region countries
- Lack of financial support due to the current economic and financial crisis
- Short term project funding cycles of public funding programmes not suitable for long term processes
- Lack of public support for the field in general

OPPORTUNITIES	THREATS
• Growing EU support in the form of the EU Blue Growth initiative under Integrated Maritime Policy and structural funds • Growing EU support in the frame of Horizon 2020 and BSR programmes • Growing support by investors • Participation at the ERA-NET • Continuous development of new advanced technologies • Growing public demand for natural products in the food, cosmetics and pharmaceutical industries • Public look upon Baltic Sea Region brand products positively	• Lack of public private partnerships, insufficient commercialisation skills, know-how and support at regional and national levels.

Knowledge Gaps

An important point in the field of Blue Biotechnology is the need to determine the best strategy to ensure the transfer of biotechnology research results to commercial products and to close the financial gap between the discovery or idea generation and the commercial application. Especially meeting the industrial requirements regarding the supply of the compound or material used in sufficiently high amounts and high quality for the desired product is an important key issue. Techniques and the knowledge in process-development necessary for scale-up the production are usually not available in the laboratories where the discovery comes from. By means of the amount of publications it can be shown that research in marine early drug development is tremendous. Nevertheless only few compounds have entered the pharmaceutical pipeline till now. One reason is the lack of interest from industry, because the new compounds are usually not patented but published by the scientists. A strong cooperation between the research institutions, industrial partners, experts in ensuring Intellectual Properties and technology transfer, with the aim of patenting and publishing without time-gap should lead to a mutual agreement of the involved partners. In case industrial partners show interest in the further development of results from the discovery stage, the need for signing contracts concerning applications for patents as well as patent valorisation between the contributing parties might hinder the product development, because of conflicting interests. By means of the amount of publications it can be shown that research in marine early drug development is tremendous. Nevertheless only few compounds have entered the pharmaceutical pipeline till now. One reason is the lack of interest from industry, because the new compounds are not patented but published the scientists. A strong cooperation between the research institutions, industrial partners, experts in ensuring Intellectual Properties and technology transfer, with the aim of patenting and publishing without time-gap should lead to a mutual agreement of the involved partners. In case of product development by the discoverers themselves there might be a problem, because know-how about marketing is missing.

It is also important to find ways to the sustainable management of scientific results so that the knowledge generated by research projects can be made easily accessible once the projects have ended.

On the scientific level several key issues exist. Among them are e.g. the need for more knowledge about the stimulation of the production of bioactive compounds and other valuable ingredients with the aim to enhance the amount but also to enhance the probability of success in finding new ingredients by cultivation-based approaches. In case of handling metagenomic data from marine samples more knowledge about transferring and expression of genes containing the information for possible new compounds or enzymes using sufficient cell-systems is an urgent demand.

Multiple other knowledge gaps also exist at the application level. For example, further research is needed on the impact on marine habitats and species of releasing bioengineered compounds and bacteria into the marine environment or on the impact of using bioengineered bacteria to optimise the fermentation process in the production of ethanol from micro – or macroalgae.

Conclusions

Even if the Blue Biotechnology field is still very much research and development focused and still shows a limited economic performance today, numerous forecasts project major growth, huge demand and correspondingly large markets.

In the Baltic Sea Region Blue Biotechnology has thus far not played a major role. However, here too it has great potential for wide implementation, based on the given expertise as well as equipment present already by now for biotechnology in general, which merely has to be put to use for the exploration from marine organisms. What is more: the Baltic Sea Region shows a great tradition in not only developing but also pursuing transnational cooperative strategies, which is a core requirement identified in this chapter for turning Blue Biotechnology research into real life applications. Based on such strategy regional disparities might also be turned into advantages, using laboratories in the new Eastern Baltic Sea countries while developing close links with the big pharmaceutical industry based more in the Western Baltic Sea region. Amplified coordination between potential contributing partners in the region would have substantial positive effects on scientific productivity, international success, foundation of new companies and growth of existing companies, financial support of investors, employment and most importantly contribute towards improved human health and environmental conditions of the Baltic Sea.

What is needed is a Baltic Sea wide strategy for the implementation of Blue Biotechnology around the Baltic Sea which is aligned with EU level developments. The strategy should be based on national action plans which take into account the respective strength of institutions and experts in the given country while also responding to most urgent market needs. Based on such a strategy a sequence of transnational priority actions could be initiated such as the establishment of a "Baltic Sea Region Blue Biotechnology Network", a centre for bioprospecting of Baltic Sea microorganisms or a distribution network for cosmetics, health care and wellness products using a Baltic Sea Region label, the scaling up of marine genomics as a source of novel enzymes from the Baltic Sea or the advancement of innovative marine technologies stemming from the region.

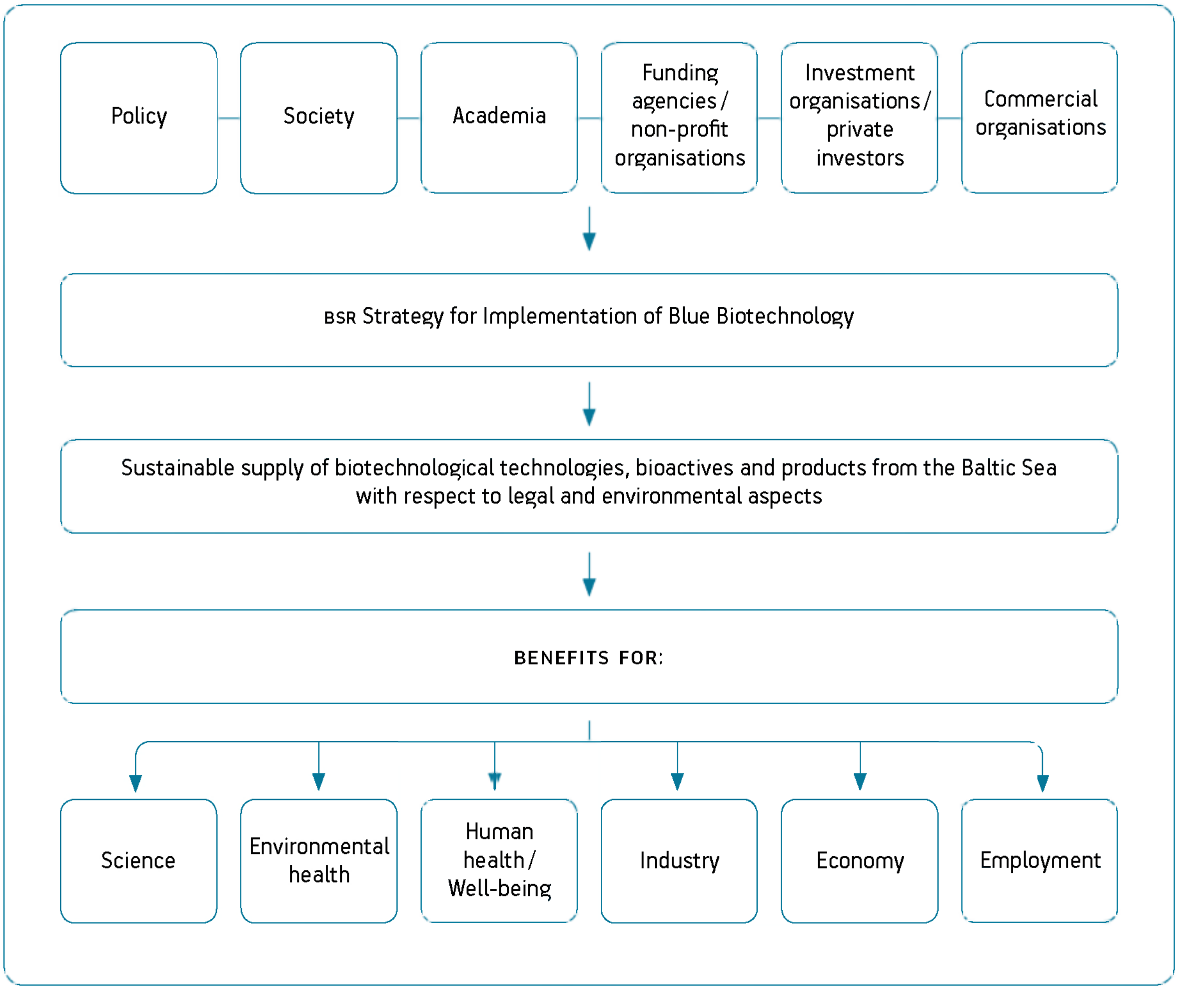
Concerted action of all contributing actors would lead to a strategy providing future perspectives and benefits for the whole Baltic Sea Region (figure 7).

Recommendations

A strategy for implementation of Blue Biotechnology within the Baltic Sea Region should include the following critical topics:

- Coordinative activities between society, policy, academia, commercial organisations, funding agencies, investment organisations and private investors are necessary to develop a strategy for successful technology transfer of scientific results to biotechnological applications

Figure 7: Wider implementation of Blue Biotechnology within the Baltic Sea Region could contribute to meet the great challenges of the 21st century.



- The strategy for enhancing activities in Blue Biotechnology should consider EU initiatives, such as the ERA-NET
- Funding by the EU within the frame of Horizon 2020 and Baltic Sea Region programmes should support the implementation of Blue Biotechnology by financing e.g. pilot plants
- All Baltic Sea Region countries have to improve their collaborative efforts and the coordination between research institutions and industry
- Blue Biotechnology roadmaps with special emphasis on regional and national key issues and topics that can only be realised in cooperation with other Baltic Sea Region countries would be a helpful tool for science, industry, politics and stakeholders
- The implementation and growth of activities in the field of Blue Biotechnology in the Baltic Sea Region would be strongly supported by the establishment of a "Baltic Sea Region Blue Biotechnology Network". Existing networks covering the fields of life science or biotechnology in general could effectively contribute to the new network, which would focus exclusively on the exploration of marine sources

- In general, there is positive public awareness of the fact that marine science as well as products and technologies from the sea provide societal benefits, an acceptance that should be taken into account and capitalised. Further initiatives to strengthen the public awareness should be implemented
- Support should be established for the infrastructure for collection and culturing of bioresources and for development of bioinformatics and databases in the Baltic Sea Region in coordination with already established or new European networks in this field
- Implementation of business lectures (e.g. project management, writing of and dealing with patents, contracts) into education of students in the year before they leave University.

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Wave Energy

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OCEAN WAVES CONSTITUTE ONE OF OUR PLANET'S HIGHLY PROMISING but still untapped natural renewable energy resources. Over 70 % of the earth's surface is covered with water. It is estimated that the potential worldwide wave power resource is 2 terawatts (TW). But the capture of the vast and endless source of clean sustainable energy generated by the waves is highly dependent on climate and technology.

Though the Baltic Sea is recognised as a basin with relatively low wave power density, it is nonetheless still auspicious for wave energy developers focusing specifically on local energy markets or on the combination of wave energy with other sea uses.

An Untapped Energy Resource also for the Baltic Sea

Introduction

Wave power, along with other renewable energy generating sources like tides and streams, is underestimated considering its advantageous physical properties and predictability. Wave energy is an energy source with high power density, a relatively high utilisation factor, low visual impact and presumably low impact on the environment.

Wave power is currently very difficult to utilise due to uncertainty in the technical solutions and the high costs of the energy harnessing devices. One of the most challenging problems is the construction of devices that can withstand rough sea conditions, such as harsh wave attacks, fouling and corrosion. The energy supply depends on the condition of the waves. While currently most devices are designed for certain regime of waves, the favourable economics of absorbing devices depend on their ability to absorb energy from a broad spectrum of waves.

There have been quite a number of technologies tested for electricity production from wave energy since the end of the last century. UK, Portugal and Norway in Europe, Australia, Canada and USA are the main countries investing into research and development of new wave energy prototypes. A large number of submerged, semi-submerged, floating and land based devices have been deployed in different parts of the world. Overall there is still little experience with full-scale devices but during the last decade an increasing number of pilot projects have started to be implemented worldwide, which will bring important developments for the future of wave power.

Usually wave energy is considered along with other related hydropower energy sources such as tides and currents. The gross global resource at the near shore is estimated to be approximately 2 TW[1] or 17.5 petawatt (PW) hour/year, which is in the range of the annual average of worldwide electricity consumption (estimated to be 2.3 TW or 20.2 petawatt hour in 2008). Europe has a wave energy resource of approximately 300 GW (or 2.6 petawatt hour/year) which is a bit less than two thirds of the current European energy demand. These numbers are purely related to wave potential; the real wave potential utilisation depends on available technical solutions and their efficiency.

The utility of the waves is usually estimated by defining the wave power density of the specific site and is either measured as wave power (kW/m) or as wave energy density (MWh/m^2). Wave power is

Figure 1: Distribution of the average annual flux of wave energy offshore, in kW per metre of wave crest. It is estimated that the energy can be exploited in an economically viable manner when levels are superior to 15~20 kW/m. Source: Wave Energy Centre.[2]

the transport of energy by ocean surface waves and the capture of that energy to do useful work, such as generate electricity. Wave energy density is a measure of instantaneous wave energy, per unit area.

Considering the wave potential in the open oceans and seas, the annual mean wave power is greatest in the southern hemisphere (~125 kW/m), while the maximum is in the North Pacific (~75 kW/m^2) (figure 1).[2]

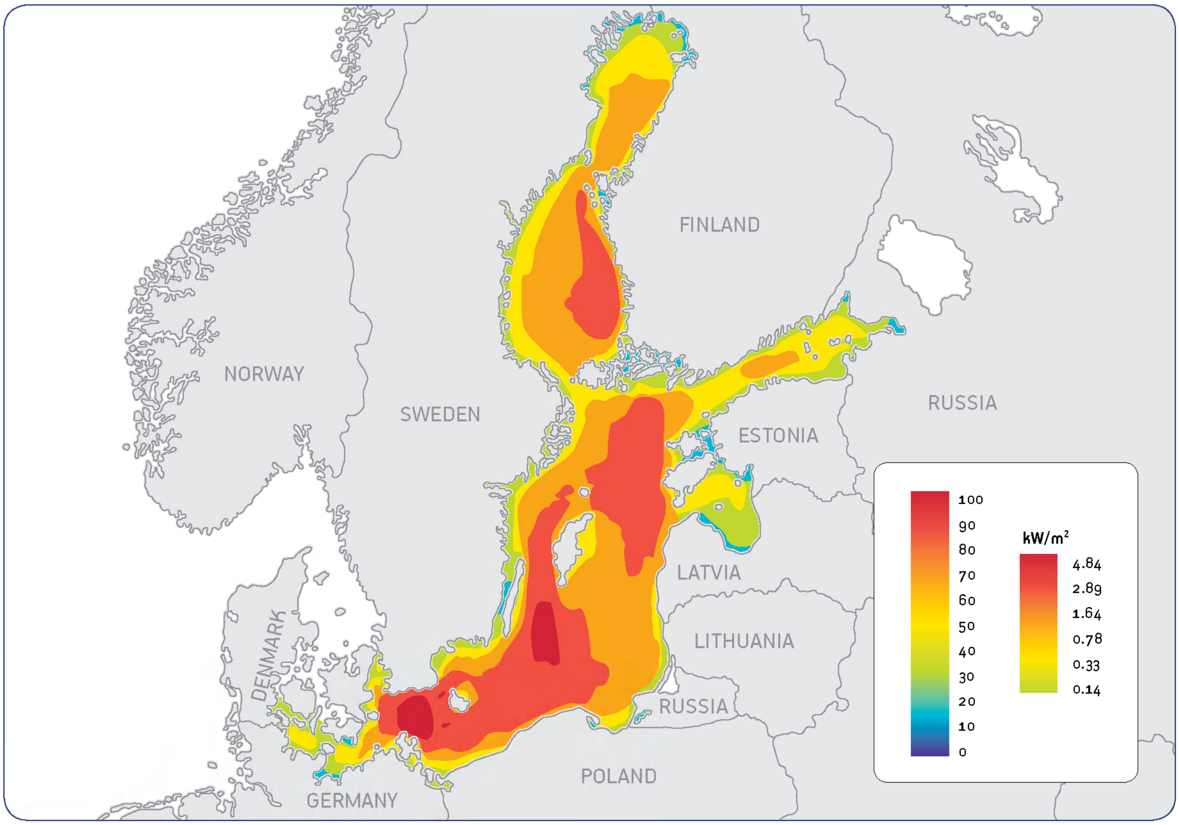
The SUBMARINER project aims to cover knowledge gap concerning the wave energy potential for the Baltic Sea. A new concept for a linear energy generator – the most suitable for electricity generation from linear motion energy sources such as waves – is being developed and tested in the Baltic waters. Newly developed technical concepts and proposed installation solutions prove that even relatively low wave energy basins such as the Baltic Sea are suitable and commercially profitable for electricity generation. Wave energy proves to be of great practical importance when providing electricity to isolated communities such as small islands or to offshore installations such as oil platforms, hydrographical buoys and navigation signs. Versatile, low cost and high capacity factor linear generators makes wave energy more attractive for the Baltic Sea and beyond.

Wave Energy in the Baltic Sea

Is Wave Energy Sufficiently Available in the Baltic?

As a semi-enclosed basin, the Baltic Sea is an area of comparatively low wave energy potential. The estimated mean wave power density in the Baltic open sea (mean annual wave height of 0.8–1.1 m and period of 4–4.6 s) is only 1.3–2.8 kW/m (or 1.7–7.8 kW/m^2). This may seem low when compared with open ocean wave power rates. Nevertheless,

Figure 2: Long-term mean wave height [cm] (isolines – every 10 cm) in the Baltic Sea in 1970–2007. Source: Raamet, 2010.[4] Average annual wave energy density in the Baltic Sea (kW/m2) based on average wave regime.



in comparison to wind power density, which is just 0.7 kW/m², waves are considerably more attractive.[3]

For rough weather conditions (wind speed ~25 m/s, mean wave height of 3.5 m, mean wave period of 8.4 s) the wave power density can reach more than 50 kW/m. This proves that annual gross wave energy may be extensive even in a shallow and relatively sheltered sea such as the Baltic Sea.

Waves in the Baltic Sea are basically wind induced. As the predominant wind direction in the Baltic Sea is westerly, naturally the highest energy density is found in the eastern part of the Baltic Sea, with relatively high density also in the south-central part (figure 2).

The most representative wave data for the northern Baltic proper stems from a directional wave rider that was operated by the Finnish Institute of Marine Research (FIMR). Although this time series (available only for 1996–2002) is not long enough to determine the long-term changes in wave properties in terms of climatological information, these data constitute the most reliable information about the main characteristics of wave fields in the open sea.

The largest average wave heights occur south of Gotland and east of Öland (around 56° N, 18° E) and in the Arkona basin where the average wave height can reach 1.01 m at locations with low depth.

The largest sub-basins, the Baltic Proper and the Bothnian Sea are characterised by a significant asymmetry in mean wave heights:

- The eastern and open parts of the Bothnian Sea have clearly higher waves (>0.8 m on average) than the western area.[5]

- In the northern part of the Baltic proper, the highest wave activity occurs along the coasts of Estonia and Latvia. The wave heights are relatively low along the coasts of Lithuania, the Kaliningrad district and north-eastern Poland.
- In the Gulf of Finland, the overall wave intensity is clearly smaller than in the rest of the Baltic Sea. The average wave heights reach 0.7 m at its entrance and in its central part but are only about 0.6 m in the rest of this water body.[6]

The wave energy density varies strongly over the year depending on the wind velocity, wind direction and the weather conditions. As shown in figure 3, the annual average for wave energy density in the Baltic Sea is estimated to be 2 kW/m^2.

Estimations prove that the potential energy generated by Baltic Sea waves is sufficient to be utilised at both small and large scales. However, the amount of wave energy that may be utilised in an economic way is dependent on a number of additional factors, not only wave regime and potential.

The main factors resulting in an economically effective project are:

- Technology selected/developed (low cost and high capacity factor)
- Energy transmission distance (distance from the main grid or direct consumer)
- Possibility to combine with other sea uses (using the same grid system, minimising the distance from the energy consumer).

Technology is the main concern of any wave energy converter (WEC) system worldwide. Up to now, Baltic Sea knowledge is being exported outside its boundaries and full scale testing is missing in the Baltic Sea.

Conditions for the transmission of energy originated at sea towards the shore in the Baltic Sea Region countries are rather favourable due to the basin's semi-enclosed nature. Furthermore, if an offshore energy grid is developed in order to meet the high demand for offshore wind energy from the Baltic Sea, the conditions for connection of the wave energy parks to this grid may become very attractive.

It is also important to consider the ice formation and drift, especially in northern parts of the Baltic Sea, as it directly affects the installations and can lead to mechanical damage. This is why additional maintenance (removing or submerging of the devices during the ice conditions) should be considered if installations are planned in the ice risk zones.

Competence Centres in the Baltic Sea Region

Even though the Baltic Sea's wave energy potential has so far not been recognised as an attractive resource, there are already a number of research institutions, energy agencies and private companies involved in the wave energy business within the Baltic Sea Region. In fact, throughout the whole of the Baltic Sea Region one can indeed find companies dealing with wave energy prototype development, some level of promotion of the ocean energy topic, universities providing study programs for young specialists as well as renewable energy sources oriented laboratories preparing special courses for the wave energy market.

Furthermore, a Danish pilot project was among the first wave energy pilots in the world. Sweden and Finland have also made attempts to test and install wave energy prototypes. A pilot of the Wave Roller prototype was tested in Finland in 2002 and in 2003. However, with the Danish and Swedish pilots being placed in the North Sea, only Finland has made attempts to test the wave energy prototypes (Wave Roller) offshore in the Baltic Sea. Thus, no substantial testing has been undertaken or is available in Baltic Sea conditions.

As there are certain technical similarities between wind and wave energy market development, the main technological research experience and knowledge is concentrated in countries with experience in offshore wind technologies, such as Denmark, Germany and Sweden. Germany, having a strong wind energy manufacturing sector, is also potentially well prepared for wave energy installation development, maintenance and supply.

Up to now, most of this experience has been exported outside the Baltic Sea Region. By promoting small and large scale concepts and testing in the Baltic Sea, waves can become a realistic source of energy as well as a growing technical industry for the Baltic Sea Region.

Technology

The first wave power device was already available as far back as 1799, but wave power technology was not sufficiently mastered until the early 1970s. Towards the end of 20th century, wave power started receiving financial support to assess the technical potential and commercial feasibility, leading to hundreds of inventions for wave power devices. As a result, a second generation of wave power devices emerged that was better designed and had greater commercial potential.

In general, the key issues affecting wave power devices are:

- Survivability in violent storms
- Vulnerability of moving parts to sea water and fouling
- Capital cost of construction
- Costs of connection to the electricity grid
- Operational costs of maintenance and repair

In the case of a wave power plant, energy losses are mainly due to friction. This friction may take place between the moving parts of the power plant, between the construction and the water and in the water itself (viscous and turbulent losses). In short: the more moving parts and sharper edges, the more energy loss.

Today there are more than 50 concepts actively being developed, mostly by small, one-product companies. There are various types of wave power devices that meet the above-mentioned challenges.[7] Most of the wave energy converters are based on turbine or piston systems, directly utilising the oscillatory motion created by the waves. It is important to notice that there is no technology available that has yet proven its efficiency over a long period of time and in various marine environments.

Spill-over devices

TAPCHAN (TAPered CHANnel) is a Norwegian system in which sea waves are focused into a tapered channel on the shoreline (figure 3). Tapering increases the amplitude of the waves propagating through the channel. The potential energy of the water trapped in the reservoir is then extracted by draining the water back to the sea through a low-head Kaplan turbine. Besides the turbine, there are no moving parts and there is easy access for repairs and connections to the electricity grid. However, shore-based TAPCHAN schemes have a relatively low power output and are only suitable for sites where there is a deep water shoreline and a low tidal range (<1 m). This technology is not applicable in the Baltic Sea.

The oscillating water column (OWC) uses an air turbine housed in a duct well above the water surface (figure 4). The base of the device is open to the sea, so that incident waves force the water inside the column to oscillate in the vertical direction. As a result, the air above the surface of the water in the column moves in phase with the free surface of the water inside the column and drives the air turbine.

Figure 3: Spill-over type wave energy device – TAPCHAN.

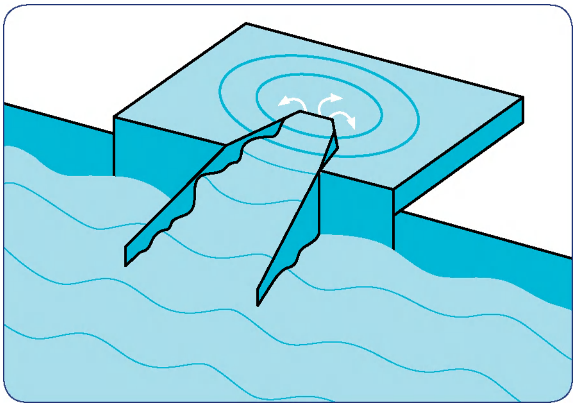
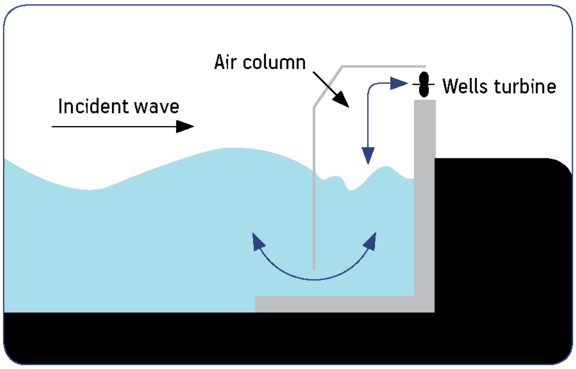


Figure 4: Oscillating water column.



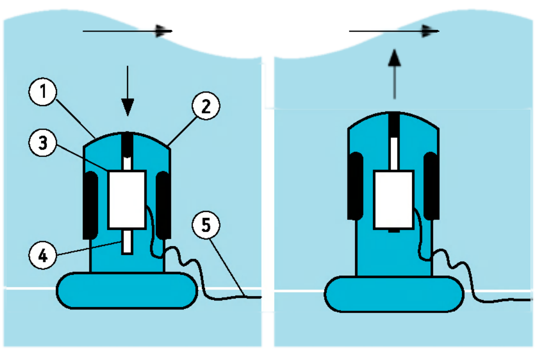
It is designed for open ocean coasts with high wave power rather than for low energy Baltic Sea coasts.

Submerged devices

Submerged devices have the advantage of being able to survive rough sea conditions on the surface. They exploit the change in pressure below the surface when waves pass overhead: the pressure is increased for a wave crest but is decreased for a wave trough. An example of this type of device is the Archimedes Wave Swing (figure 5). The AWS is a submerged air-filled chamber that oscillates in the vertical direction due to the wave action. The motion of the floater energises a linear generator tethered to the sea bed. The AWS has the advantage of being a 'point' absorber, i.e. it absorbs power from waves travelling in all directions and extracts about 50 % of the incident wave power. Other advantages are its simplicity, its lack of visual impact, and quick replacement and cost effectiveness in terms of power generated per kg of steel. A pre-commercial pilot project in Portugal has three AWS devices (8 MW).

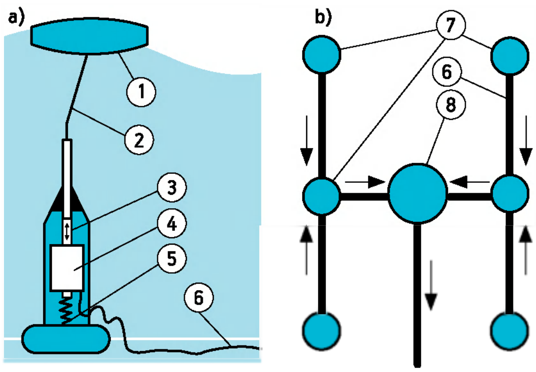
The recently implemented wave power project Lysekil in the west coast of Sweden is to test a new concept of unique piston-driven generators. A so-called linear generator stands protected on the seabed and is driven via a rope to a buoy on the surface (figure 6). Several generators can be combined into groups, some 20–100 m beneath the surface, using standard cables on the seabed. Generated alternating power is converted into direct current. This system with buoy, rope and generator is expected to be cheap, sturdy, environmentally benign and able

Figure 5: Submerged device – Archimeds Wave Swing.



1 moving floater,
2 camera with air
3 electric generator stator
4 linear generator moving part,
5 electric cable

Figure 6: Lysekil project a – wave energy converter module structure, b – modules array.



1 buoy
2 flexible rope
3 piston of linear generator
4 stator
5 spring
6 electric cable
7 converter
8 central substation

to cope with the extreme conditions at sea (http://www.el.angstrom.uu.se). Both technologies (AWS and Lysekil) are suitable for any marine environment, including Baltic Sea. The main concern is isolation of the electric part under the water.[8]

There are also semi-submerged solutions available. The mainly shallow water related concept of the oscillating surge converter extracts energy from wave surge at water depth less than 20 m. As waves approach more shallow water, the circular movement of water particles becomes more elliptic and the water movement closer to the seabed becomes a back and forth motion. Oscillating wave surge converters (OSC) use this oscillating back and forth motion to extract energy. The concept was and is-to-be tested in several projects such as Langlee E2 in Norway, 2.5 MW Oyster in Scotland and Wave Roller in Finland. Even though it is designed for shallow waters, this technology might be difficult to use in the very extensively used and also protected Baltic Sea nearshore environment.[9]

Floating devices

The Salter duck floating device was developed in the early 1970s (figure 7). The complete system envisaged a string of Salter ducks of several kilometres in total length parallel to a wave front. A spinal column of 14 m diameter used the relative motion between each duck and the spine to provide the motive force for generating power. The device had an efficiency of around 90 % and thus provides a useful benchmark for comparing the efficiencies between all wave power devices.

A recent type of semi-submerged serpentine construction is the floating device Pelamis (figure 8). It consists of a series of cylindrical hinged segments that are pointed towards the incident waves. As waves move along the device, the segments rock back and forth and the relative motion between adjacent segments activates hydraulic rams that pump high pressure oil through hydraulic motors and drive electrical generators. A three-segment version of Pelamis is 130 m long and 3.5 m in diameter and generates 750 kW. The system is most promising for high wave potential areas. The economic feasibility for the Baltic Sea conditions is yet to be tested.

Figure 7: Floating device – Salter duck.

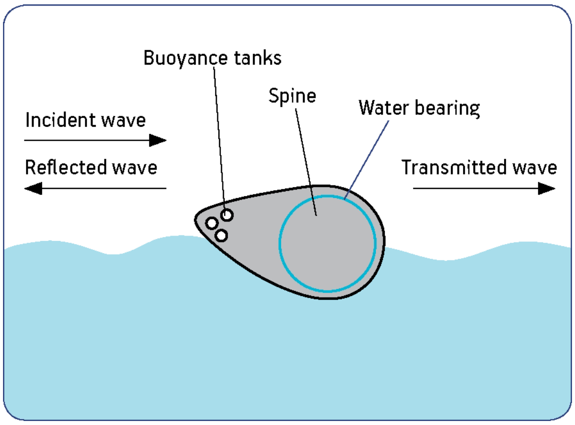
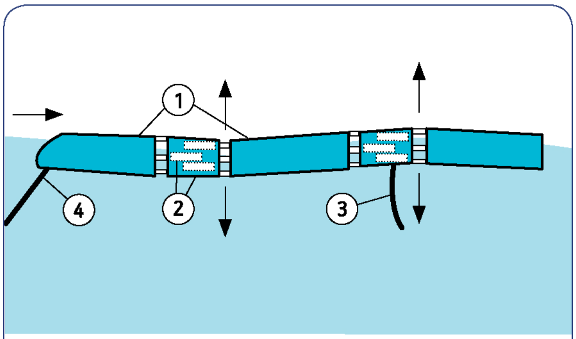


Figure 8: Pelamis.



1 cylindrical hinged segment
2 hydraulic ram
3 power cable
4 anchor

REGIONAL CASE

A New and Innovative Device

The wave energy concept under development in the SUBMARINER project differs from the above-mentioned devices. Firstly, it is more focused on wave energy conversion into electricity effectiveness (linear movement generator development, figure 9). In fact, could be used in any of the concepts described above. Secondly, the concept is intended to meet small-scale utilisation projects, which have not yet been sufficiently covered. This might unlock the opportunities for other "low wave energy" basins in Europe and worldwide.

The linear generator is oil – and vibrations-free as well as high capacity due to a unique arrangement of magnets. It is thus suitable for use in small and big scale wave energy conversion systems. The first attempt of deployment in an almost 100 % water isolated floating carrier (figure 10) proved the applicability of the concept. The device lacks any flexing parts as well as any electric parts exposed to the sea water, since the generator is sealed inside a floating device, a ridged structure made to resist any ocean conditions, bio fouling and corrosion.

Currently, the second small-scale prototype is being developed. The linear generator is supposed to ensure the additional electric power supply for Single Point Mooring Buoy.

The main focus of further research is on development of a stand-alone array of linear generators that can be placed inside any device having up-down/forth-back motion. The concept also allows for the use of the existing offshore infrastructure (wind towers, buoys oil platforms, etc.) for deployment of the wave energy converters and use of the existing transmission system.

Figure 9: Linear movement generator developed by A. Pašilis, CORPI, 2011.

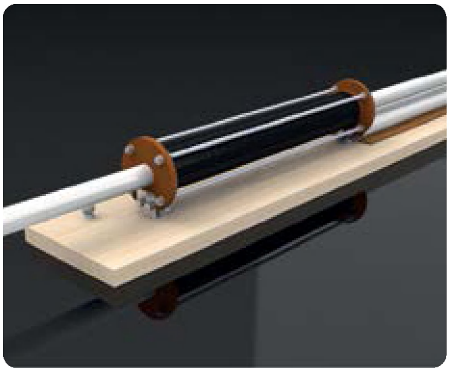


Figure 10: Floating device with installed linear movement generator.

Environmental Assessment

A standalone deployment of wave energy converter devices can cause significant disturbance to the local habitat in particular during the deployment phase when submarine and intertidal construction work is needed to connect to a shore-based grid. Combining the deployment of wave energy devices with existing offshore infrastructure such as wind parks or monitoring buoys offers a lot of synergies for harnessing renewable energy and it reduces significantly the unfavourable impact on the environment by taking advantage of existing infrastructure to connect to the grid. To illustrate this point, the environmental priorities that are impacted by a standalone deployment and a combined wave / wind park deployment are compared below (Table 1). In the case of a standalone deployment, the environmental priorities that are unfavourably impacted are bathing water quality, water

Table 1: Overview of the impact of deploying, operating and decommissioning a standalone wave device and a combined wind/wave device in the Baltic Sea Region on environmental objectives and priorities.

Environmental Objective	**Environmental Priority**	**Standalone Wave**	**Combined Wave/ Wind**	**Comments related to standalone**
Water quality	Bathing quality			
	Water transparency	🔴	○	construction
	Eutrophication			
	Biogeochemical cycles	🔴	○	construction
Habitat / Species protection	Food web dynamics			
	Biodiversity			
	Benthic habitats	🔴	🟠	construction
	Bird habitats	🔴	○	construction
	Fisheries	🔴	🟠	construction
	Marine mammals	🔴	🟠	construction & deployment
	Marine noise	🔴	🟠	construction & deployment
Coastal protection	Coastal morphology	🟠	○	construction & deployment
	Scenery	🟠	○	construction, deployment & decommissioning
Climate protection	CO_2 Emissions reduction	🔵	🔵	Renewable energy

🔵 strongly supportive
🔹 moderately supportive
🔴 strongly not supportive
🟠 moderately not supportive
○ neutral
? gaps in information;
blank not applicable

transparency, biogeochemical cycles, benthic and bird habitats, fisheries, marine mammals, marine noise, coastal morphology and scenery. All of these impacts become either neutral or are moderated when a combined wave / wind park deployment is considered, making it an attractive possibility. The extent of the environmental impacts will ultimately depend on the type of device being deployed.[10]

Water Quality and Habitats

For a standalone deployment, both marine and terrestrial environments are impacted. Construction work at sea, on land and in the intertidal environment is needed. The structure holding the wave energy device needs to be anchored to the seabed and submarine electricity cables are needed to transmit the energy to the shore and connect to the electricity grid. The submarine cables are typically entrenched in the seabed to shore areas and then buried above the low water mark to a land-based substation. This disturbance during the construction phase can lead to temporary increase in sedimentation, decrease in water transparency and losses to benthic, pelagic and intertidal communities.

For a combined deployment, the areas of concern are reduced to the impact of marine noise and vibrations on marine mammals, fish and benthic communities. The impact of noise disturbance caused by operation of the wave energy device and by the mooring systems associated with them is a concern for marine mammals primarily, but also for fish to a lesser extent. With some types of wave energy devices, there may also be issues with electromagnetic fields, vibrations and oil leakage impacting marine mammals' sonar capacities, fish reproduction and benthic macrofauna communities. However, the wave energy concept under development in the SUBMARINER project is oil – and vibrations-free. Physical damage to mammals arising from collision with the wave energy device and mooring system is also a possibility.

Coastal protection

The physical presence of a water energy converter structure fixed to the seabed has the potential to cause physical changes to normal coastal processes such as scouring of the seabed adjacent to moored systems or buried or protected cables. If cables are deployed above rocky seabed they will require some form of protection such as rock armouring. This could result in the formation of artificial reef structures that may also influence coastal processes in the area but on the other hand can have a positive impact on biodiversity.

The scenery may also be impacted by the physical presence of the wave energy device (size matters), the presence of construction vessels, plant and machinery during submarine construction and the construction and physical presence of the substation and overhead grid connection.

Climate Protection

The potential to favourably impact climate protection by reducing CO_2 emissions could be realised with standalone and combined deployments through capturing a renewable energy source. The

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

While wave energy is an attractive source of renewable energy, the deployment, operation and decommissioning of a standalone wave energy converter involves certain disturbance to the local habitat. For combined wind/wave deployments with existing installations, the environmental impact is negligible, making it especially attractive in lower wave energy environments such as the Baltic Sea Region as an additional source of renewable energy to support local infrastructure (e.g. oil platforms, environmental monitoring buoys, navigation signs).

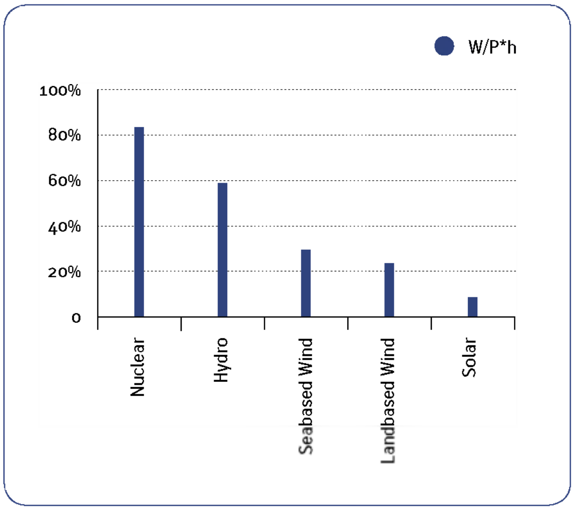
combined deployment has the added potential of supplying its host with an energy source making the whole combined operation independent of other energy sources. The scale of this potential impact will not be known though until the technology, location and life cycle assessment of the activity is better understood.

Socioeconomic Aspects

Economic Potential

The potential worldwide wave energy economic contribution to the electricity market is estimated to be in the order of 2,000 TWh/year – about 10 % of the world electricity consumption – and to have an investment cost of € 820 billion.[1] The electricity generating costs from wave energy converters have shown a significant improvement in the last twenty years, reaching an average price of approximately € 0.08 per kWh at a discount rate of 8 %. Compared to the average electricity price in the EU, which is approximately € 0.04 per kWh, the price of electricity produced from wave energy is still high. It is, however, forecasted to decrease as the technology further develops.[11]

Figure 11: Utilisation factor of conventional electric energy production systems.[8]



The common understanding of energy conversion is that the utility pays for the installed power (P, in kW) and gets paid in yearly produced energy (W, in kWh). The best performing Swedish windmill today has a utilisation factor of 29 %. In theory, hydropower (all types of water related power) has a much higher degree of utilisation, estimated to be up to 60 % in Sweden (Figure 11). For wave and tidal power, the capacity factor based on existing knowledge and experience is typically between 30–40 % of the rated power.[12] The same is true for the estimated utilisation capacity for the Pelamis offshore wave energy converter, which ranges between 25–40 %, depending on the conditions at the chosen project site (source: www.pelamiswave.com/pelamis-technology). Other sources reveal that the utilisation factor for wave power – the ratio of average generated power to installed power of the power plant – is expected to be as high as 50 % or 4,380 h/year.[13]

Wave Energy Development Costs

Due to the harsh marine environment and the early level of industrial development, estimates of investment, operation and maintenance costs of marine energy technologies are highly uncertain. In general, it is assumed that total costs to get from idea (scientific research and R&D) to a full-scale MW-size prototype development (technical implementation) are in the order of € 30–35 million. The estimated cost of a full-scale prototype development (technical part only) is reported to be one third of total investment costs or around € 7–10 million per MW.

The investment costs of currently implemented projects show that wave power installation cost is currently between € 5.4–7.2 per MW. It is projected to drop to about 30 % in 2020 and by another 20 % by 2030.[14, 15]

Financial estimations provided by Ernst & Young[16] where divided into "CAPEX" costs, which include construction, electrical systems infrastructure and pre-development costs (figure 12), and "OPEX" costs, which include operation and maintenance, insurance

Figure 12: Wave CAPEX.[15]

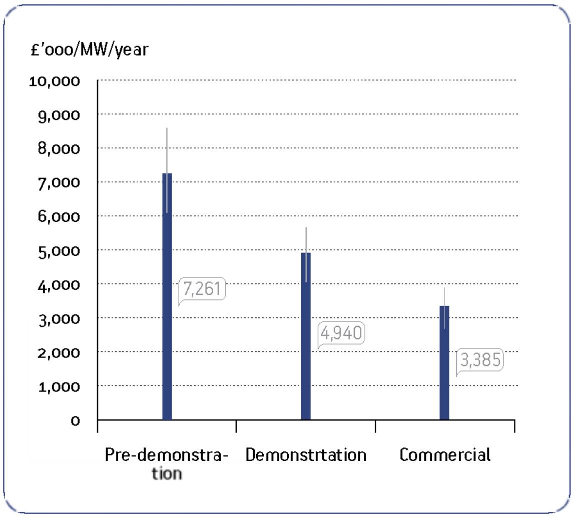
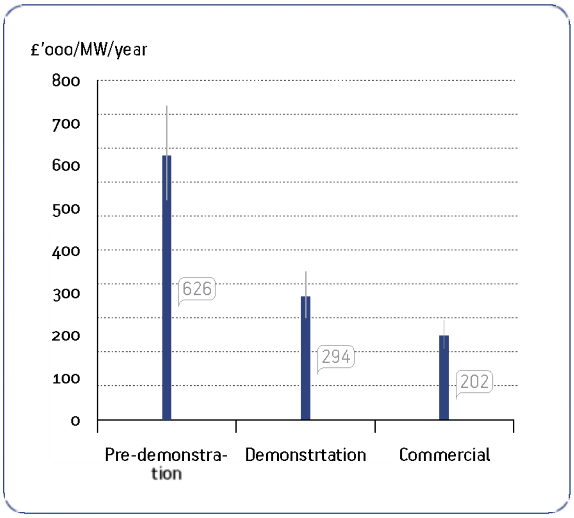


Figure 13: Wave OPEX.[15]



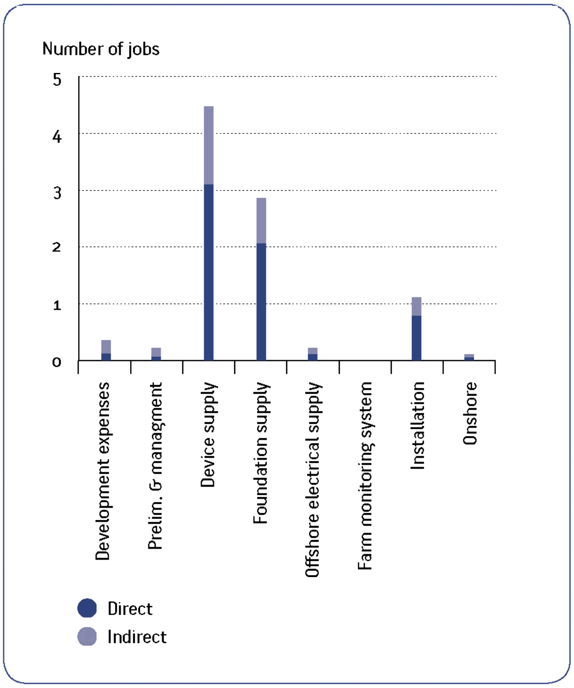
and decommissioning and other costs such as rent, transmission network use and national grid charges (figure 13). The estimates clearly show that research and development is much more expensive than construction of the prototype itself and much less expensive than the commercial implementation, when all technical details are clear and mistakes minimised.

Job Creation Opportunities

Parallels can be drawn with the growth of the wind industry. Wind energy is a very recent commercial development which has very rapidly become a € 2.2 billion per year industry, employing about 40,000 people worldwide and with growth rates of 10 % annually. Denmark, whose government sought to establish its country as an early world leader in wind energy, now employs over 12,000 people in this industry and its export of clean technology accounts for € 7.1 billion annually. In Germany export of wind technology alone is worth over € 5.1 billion.

As stated by the European Ocean Energy Roadmap 2010–2050[17], the manufacturing, transportation, installation, operation and maintenance of ocean energy facilities will generate revenue and employment. It is anticipated that approximately 10 to 12 direct and indirect jobs would be created for each MW of ocean energy installed. Based on the projections for installed capacity, it is expected that by 2020 the ocean energy sector will generate over 26,000 direct and 13,000 indirect jobs. Waves alone

Figure 14: Job creation per MW of wave energy capacity installed.



could contribute with 6–7 direct and indirect jobs created for each MW (figure 16).

Another estimate provided by the Scottish Government's Marine Energy Group Roadmap suggests that the marine energy industry could provide up to 12,500 jobs, contributing £ 2.5 billion to the Scottish economy by 2020. The installation of one full-scale wave energy device in the Orkney Islands in Scotland resulted in direct spending of more than € 1 million in the local economy.

Site selection

The site selection for big-scale deployments of wave energy devices depends on environmental conditions, economic efficiency as well as availability of space.

The depths and substrate of the seabed are of key importance for the selection of anchoring technology. With devices placed on the seabed, the local geology and seabed conditions will affect the possibilities of placing WEC units at specific sites. For example, a point absorber could be mounted on a concrete foundation, which requires a flat seabed, commonly clay, mud or sand.

Further boundaries are set by economical feasibility, i.e. distance from land and the electricity infrastructure grid. The location of commercial wave array parks may be constrained by a number of factors, including physical conditions and ongoing and planned human activities, such as commercial fishing, shipping channels, areas of military interest, sites of marine archaeological importance and valuable biological areas, including marine reserves.

Shoreline devices have the advantage of being close to the utility network and thus are easy to maintain. In general, these devices are site-specific and depend on the shoreline geometry and geology and the preservation of coastal scenery, so they cannot be designed for mass manufacturing.

Near-shore devices are also deployed in relatively shallow water and attached to the seabed, which gives them a suitable stationary base against which an oscillating body can work. Like shoreline devices, a disadvantage is that shallow water leads to waves with reduced power, limiting the harvesting potential but on the other hand they are easier to maintain.

Offshore devices are generally located in deep water and can harvest greater amounts of energy due to the higher energy content. However, offshore devices are more difficult to construct and maintain. Given the greater height and energy content of the waves, they need to be designed to survive more extreme conditions, which adds to the construction costs. Despite this, it is argued that with more powerful waves, floating devices in deep water offer greater structural economy.

Deskwork investigations and prototype development results shows that wave power installations can be placed anywhere in the marine environment. The balance of investments (site, technology and scale selection) versus revenue (efficiency of the device and support schemes) of produced electricity is the only issue to be focused on.

- From the energy potential point of view, the offshore zone has the maximum wave potential but deployed wave energy converters face higher mechanical loads, especially during storms. Those areas are suitable for large-scale projects due to the higher investments necessary to develop wave power generators withstanding and utilising the energy generated by the biggest waves. Connection to the grid and maintenance costs are also rather expensive.
- The near-shore environment, which is quite close to the offshore conditions (energy drop of not more than 10 %) has certain advantages: waves often have one prevailing direction, which allows proper orientation of the equipment. Near-shore conditions are considered to be those that correspond most closely to those found in the shallow Baltic Sea.
- Onshore wave energy converters are either attached to the shore or they are part of the coast. In general, this type of installations is technically the most difficult to sustain due to the big

destructive power of the braking waves impacting the shores.

- The concept of versatile stand-alone linear generator arrays being developed within the SUBMARINER project allows for utilisation of the energy generated by waves in both small and large-scale projects in the Baltic Sea and beyond.

Regulatory Framework

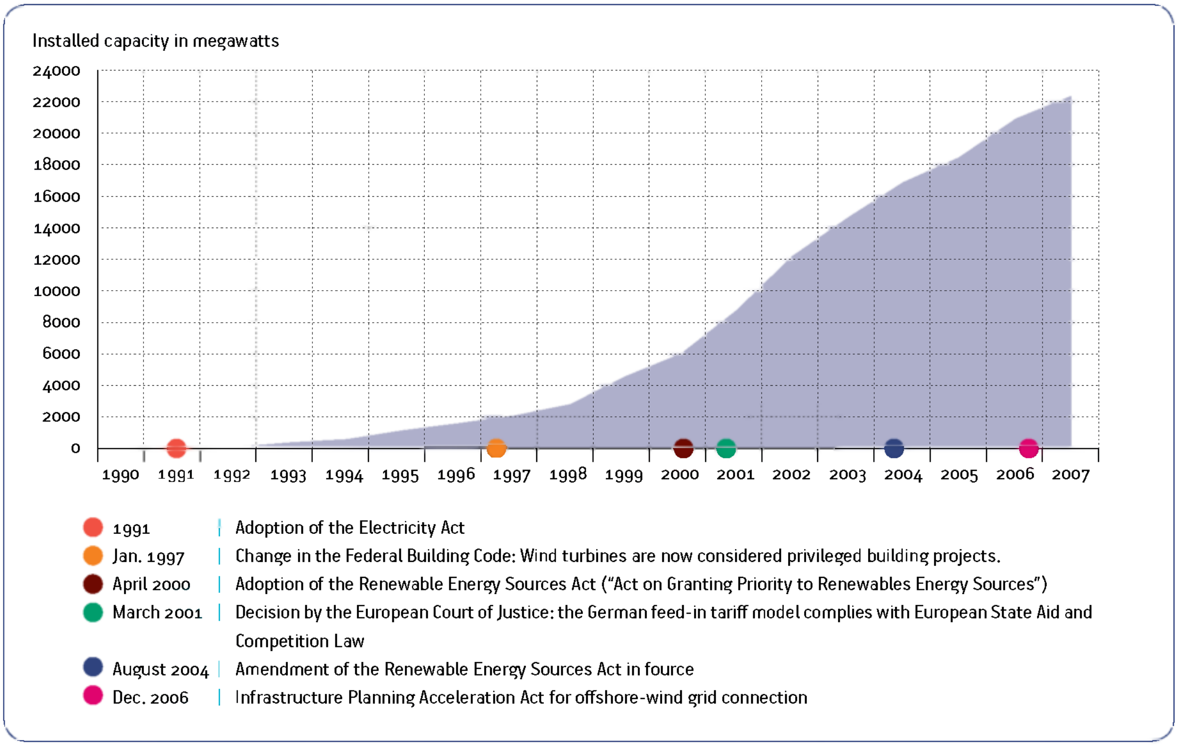
Political Strategies

Wave energy is an integral part of the EU renewable energy directive. As per the article in Directive 2009/28/EC: "It is necessary to set transparent and unambiguous rules for calculating the share of energy from renewable sources and for defining those sources. In this context, the energy present in oceans and other water bodies in the form of waves, marine currents, tides, ocean thermal energy gradients or salinity gradients should be included".

Various other EU legal acts and supporting mechanisms have a direct impact on the development of the offshore renewable energy sector (figure 15). The European Ocean Energy Roadmap 2010–2050, published in May 2010, foresees the generation of over 15 % of the EU energy demand, the creation of over 470,000 new jobs and the avoidance of over 136 MT/MWh of CO_2 through the use of European ocean energy resources with a total projected installed capacity of 188 GW by 2050. Of the Baltic Sea countries, only Denmark was included in this calculation with 0.5 GW, mainly stemming from the North Sea.

In addition, countries around the North Sea (Ireland, Scotland) have adopted strategies fostering the development of renewables at sea and

Figure 15: European Ocean Energy Roadmap policies support growth Source: European Ocean Energy Roadmap 2010–2050.



particularly ocean energy including waves, currents and tides.

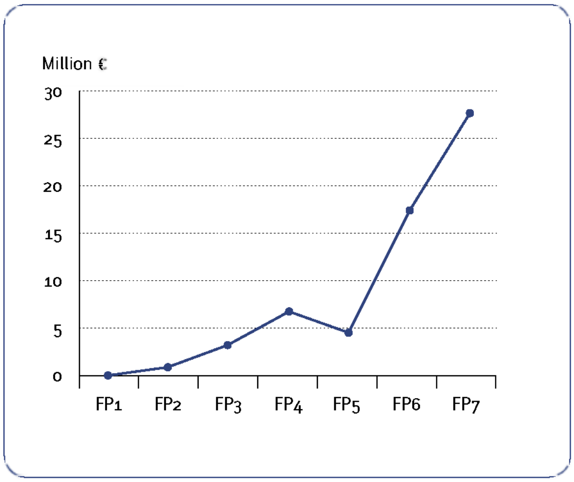
However no such strategy exists so far for the Baltic Sea Region or at any individual Baltic Sea country.

Research Funding

European research funding on ocean energy began back in the 1980s and has increased significantly ever since, in particular during the last decade (figure 16). In total, more than € 55 million have been spent so far to support research and advance knowledge in marine power production testing and optimisation, to develop cost efficient floating devices for wave energy conversion into electricity, to implement pilot projects to exploit marine currents, to develop power production from salinity gradients and to further the development of offshore platforms for wind and ocean energy.

At a national level, the UK has the most comprehensive marine energy support regime in the world. The Scottish Ministers' Wave and Tidal Energy Support Scheme, with a total funding of £ 13 million, provides grants to businesses to support the installation, commissioning and deployment of pre-commercial wave and tidal electricity generating devices at the European Marine Energy Centre in Orkney. Additionally, the Scottish Government has launched the Saltire Prize (£ 10 million) for the best commercially viable wave or tidal stream energy technology. Furthermore, in June 2011 the Department of Energy and Climate Change, UK, announced its investment of up to £ 20 (€ 25) million in wave and tidal power to help develop marine energy technologies from the prototype stage to demonstration of arrays of devices.

Figure 16: European funding for ocean energy between 1990 and 2009 (European Ocean Energy Roadmap 2010–2050).



No such funds on a national level exist in any of the Baltic Sea states yet.

Planning and Licensing Procedures

The process for permitting wave energy developments does not differ much from any other offshore activity to be placed at the sea (most notably offshore wind energy). However, countries differ in terms of existing legal procedures, responsible authorities and complexity of the process. For example, the Danish Energy Agency serves as a "one-stop-shop" for permitting in Denmark, which substantially speeds up processes compared to other countries.

The procedure in general always follows the following basic stages:

- Site selection
- Strategic Environmental Assessment (and/or EIA)
- Technical projects for installations and connection to the grid.

SWOT Analysis

STRENGTHS	WEAKNESSES
Steadier and more predictable energy production, both day to day and season to season Relatively smoother and more consistent power production with estimated energy capacity factor up to 50 % Potential to reduce coastal erosion by absorbing energy generated by waves Suitability for small and big scale energy projects to be developed close to the end user	May conflict with the fishery sector if an uneven distribution of offshore wave energy converters reduces fishing grounds Limited knowledge available on the technical potential at the Baltic Sea; industry is mainly focused on North Sea conditions Economic estimates are not yet reliable as there are no operating devices in the Baltic Sea Region, hampering potential investors' support May have negative local impacts depending on technology selected during construction and operational phases (sediment dispersion, introduction of hard substrates, noise, vibration or electromagnetic fields, introduction of new habitats, over-building, etc.)
OPPORTUNITIES	**THREATS**
Growing demand for energy from alternative sources Growing prices for traditional energy carriers EU support via creation of energy and climate change policies, EU Blue Growth initiative under Integrated Maritime Policy and structural funds Growing development of high technology Global drive towards sustainable development Growing support for decentralised network economies Possible synergies due to plans to expand offshore wind power in the Baltic Sea	Expected changes in Baltic hydro-meteorological conditions due to climate change Increasing nature protection requirements Lack of political support embedded in the national energy policies ensuring stable level of prices for energy produced from renewable sources Lack of public awareness and as a consequence support Lack of financial support

Knowledge Gaps

No wave energy converters are yet used in a permanent manner in a commercial operation anywhere in the world. However, globally, the technology is at an advanced stage of research and deployment and offers considerable promise, in particular in regions where significant wave activity occurs. Test sites are currently being operated in the Northeast Atlantic. Many of the gaps in information are related to the testing of technology in real environments and understanding the full wave energy potential of a proposed deployment site. The main technical problems, advantages/disadvantages related to each of the developed prototypes are well known. Physical resistance, corrosion, sustainability of the moving parts and bio-fouling are the main technical problems that have to be solved in order to make devices economically feasible to develop, operate and maintain.

A special focus on relatively lower energy basins is missing, as is research on small-scale project opportunities (alone or in combination) to harvest different levels of wave power potential. Taking into account that most of the devices have not yet been tested in the specific Baltic Sea environment, we can safely assume that knowledge in this region is even more limited.

Conclusions

The Baltic Sea, as a relatively low wave energy area, can serve as a pilot region for a break-through in small scale wave energy converting systems.

Given the pressures for using space in the Baltic Sea Region, combined wave energy converter deployments with existing infrastructure are particularly attractive.

Recommendations

- Wave energy in the Baltic Sea should be encouraged and financed to a greater extent by EU research funds and national governmental subsidies
- More Baltic Sea specific research is needed to investigate the resource potential and environmental impact
- More research is needed for further development and testing of technology suitable for relatively low wave energy conditions
- Networking activities should be supported in order to establish knowledge and technology transfer between countries
- Legal regulations and maritime spatial planning should be in place in order to make development of offshore wave energy projects realistic
- More research is needed to further develop combined wave energy converter deployments with existing installations to support local infrastructure.

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Sustainable Fish Aquaculture

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ACCORDING TO THE DEFINITION OF THE FOOD AND AGRICULTURE ORGANIZATION (FAO) OF THE UNITED NATIONS, fish farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.

Sustainable fish aquaculture translates into the application of a technology that does not pollute the marine environment, does not deplete or permanently damage other marine species or ecosystem components, uses a sustainable feed-supply chain, is not dependent on the use of excessive fossil fuel based energy and complies with the FAO Code of Conduct for Responsible Fisheries and Aquaculture.

New Opportunities Based on More Sustainable Technologies

Introduction

The aim of the current chapter is to point out the state of the art of fish aquaculture in the Baltic Sea Region with "netcages" as the currently still dominating production technology. It discusses and compares the potential of new technologies and the future possibility to produce fish in a more sustainable manner.

A stagnating fisheries production caused by globally overexploited fish stocks and a rise in demand for seafood have resulted in a spectacular growth in production in the aquaculture sector, which is now the fastest growing food production sector with an average worldwide growth rate of 8.8 % a year since 1980.[1] Since 2000 the contribution of aquaculture products for human consumption has increased from 30 % to nearly

Figure 1: Global production of aquatic species (Data: FAO).

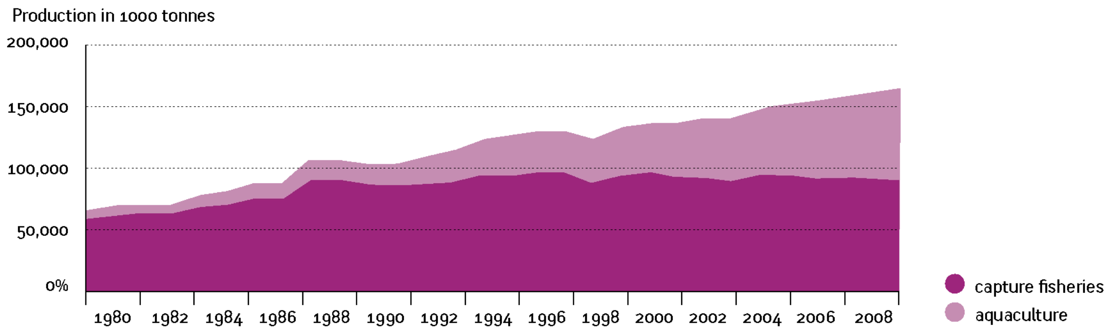
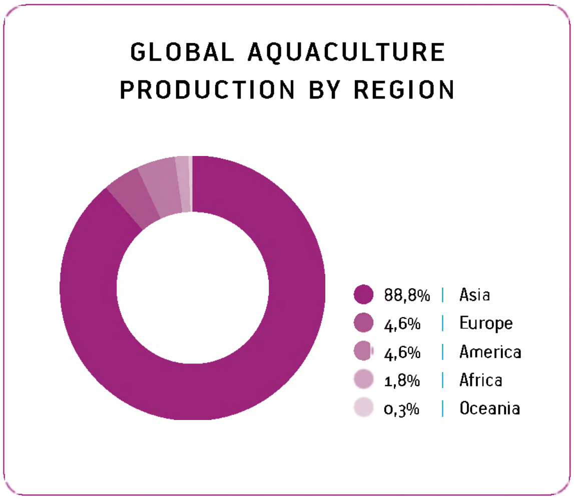


Figure 2: Global aquaculture production by region (Data: FAO).



50 % of global aquatic food production, showing enormous economic opportunities.

Yet compared to Asia and South-America, overall aquaculture production in the EU has stagnated. Nowadays the EU aquatic food market relies mainly on imports to cover a growing demand.

At the same time, aquaculture raises a number of challenges in regards to the sustainability of production. During the last decade, there has been much debate about what sustainable fish aquaculture is and how it could be realized. From a practical point of view measurable indicators of sustainability in three different areas were determined.

- **Environmental concerns** deal with the quantity of land, water and energy used; water quality, release of alien species and effluents.
- **Economic issues** focused on profitability, market demand and improved feeding efficiency.
- **Sociological interests** centered on employment, local concerns such as residency / ownership and regional sources of inputs (feed, labour, money).[2]

Generally the EU has recognised the important role of aquaculture in terms of food production and its contribution to reducing and eventually eliminating overfishing of wild stocks and has induced significant progress to ensure environmental sustainability, safety and quality of aquaculture production.

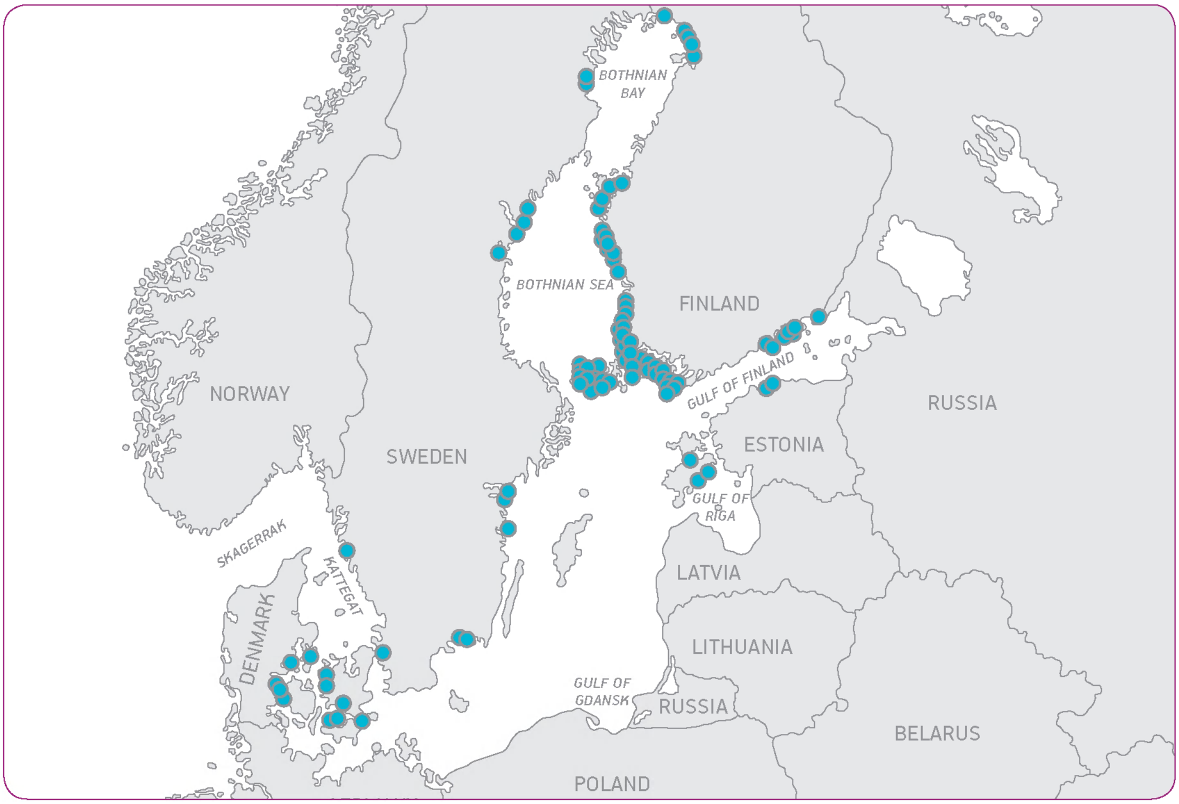
On the global scale, the Baltic Sea Region's marine aquaculture sector has so far only played a very minor role. Nevertheless the Scandinavian countries have a significant tradition in marine aquaculture with a small but stable fish production. The dominating production technology in use is based on "open net cage" systems, which have, in recent years, raised increasing concerns on environmental sustainability.

However, the potential to develop the industry in a more sustainable manner throughout the Baltic Sea Region does exist. Even though natural conditions may not be ideal in the region, the search for methods to decrease import reliance and ways to achieve fish restocking are important motivators for the further development of the sector.

Emerging technology could not only allow for a sustainable fish aquaculture industry in the Baltic Sea, but also permit the introduction of new fish species to reduce imports and increase freshness of the product for consumers. Furthermore, so-called hatcheries, where high water quality standards necessary for fingerlings and fish hatchling production can be assured, may make an important contribution towards restocking of fish within the Baltic Sea.

A dynamic research and technology sector, advanced equipment, trained and qualified entrepreneurs, a solid environmental and health protection legal framework and changing consumer demands towards more eco-friendly products are all strengths which can help further develop this industry. Baltic countries with a longer history in marine fish farming, such as Sweden, Finland and Denmark, could choose to strengthen and increase sustainability of their industry by introducing innovative technology to already existing farms, while at the same time establishing new emerging systems. Other countries where marine fish aquaculture is not yet established due to a lack of suitable sites, may seek to introduce aquaculture systems that are land-based and therefore independent from sites with suitable hydrological water conditions.

Figure 3: Marine and costal fish aquaculture operations in the Baltic Sea Region. Data from WWF.



Fish Aquaculture in the Baltic Sea Region

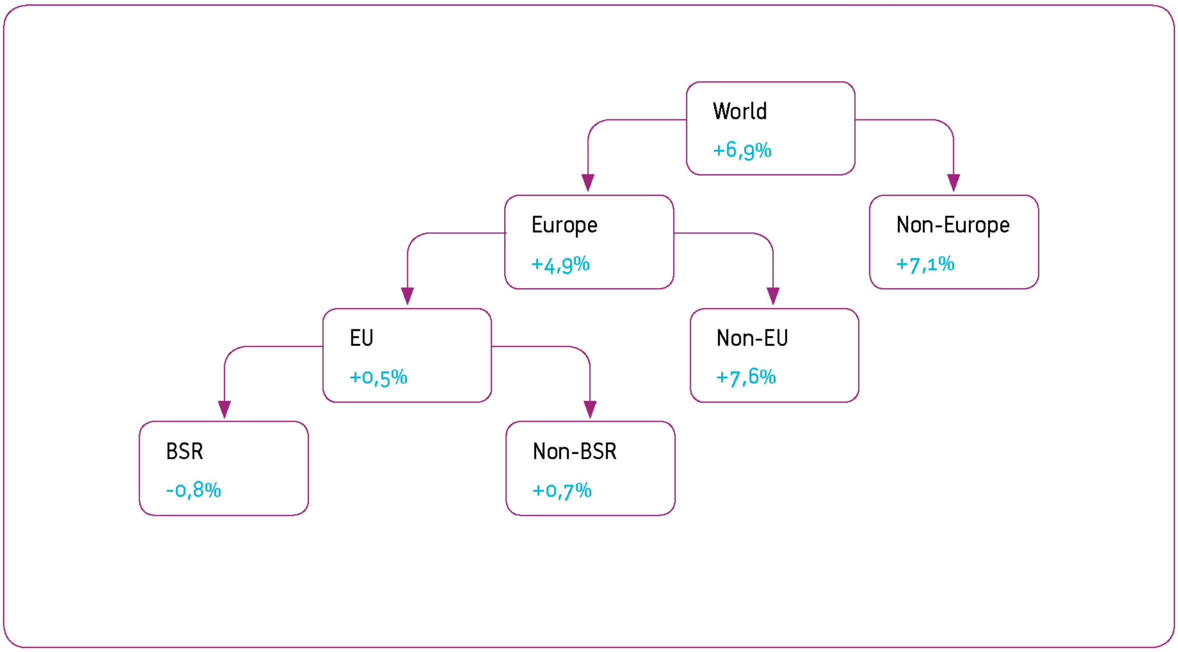
A North-South Divide

Due to its special characteristics as a brackish inland sea, with a lower water salinity than that of ocean water, the conditions for fish aquaculture in the Baltic Sea are different to those in other marine regions. As a consequence, marine aquaculture in the region is specialised on aquatic species that are adapted to local water conditions. Even within the Baltic Sea the range of salinity varies, being generally higher in the western Baltic Sea than in the eastern parts. This naturally has an effect on the potential fish species that can be reared in marine aquaculture systems in the Baltic Sea Region. Turbot for instance need higher salinities, whereas salmon trout can tolerate a wider range of salinities found in the Baltic Sea, which is why the region has specialised on production of this particular species. Moreover the availability of sites with suitable hydrological conditions is limited to certain regions, for example in sheltered coasts, gulfs and bays, mainly to be found in Scandinavian countries.

As a consequence of these difficult natural conditions, marine fish aquaculture in the Baltic Sea plays only a minor role in worldwide aquaculture production and is, contrary to global developments, even in decline. With about 27,000 tonnes (2009) of food fish and by-products produced in marine and brackish environments of the Baltic Sea, the region only had a share of under 0.1 % of global aquaculture production. Still, this production was estimated to be worth about € 77 million (2007).[3]

Certain Baltic countries, notably Finland, Sweden and Denmark, have a relatively more developed marine fish farming sector. All three have a

Figure 4: Growth of world aquaculture since 2000, divided by region. (Source: BESTAQ project).



strong tradition of salmon trout (also known as rainbow trout when cultivated in fresh water) farming reaching sometimes as far back to the beginning of the 1900s. During the 1980s and 1990s production declined in these countries but it has been growing again and levelled off in recent years.

Marine fish aquaculture along the German Baltic Sea coast used to be encouraged by former East Germany and prior to reunification, but subsequently the activity disappeared almost entirely. Nowadays only a few fish farms remain in the Kiel Bight and along the coast of Mecklenburg-Vorpommern, producing less than 100 tonnes of salmon trout annually.

Marine fish aquaculture in Poland, Lithuania, Estonia and Latvia is extremely limited and most of it is for restocking measures. There are also little prospects for nearshore aquaculture systems as the coastline is shallow, eutrophic, often polluted by algal blooms and exposed to storms and wave action. Furthermore, extensive ice layers in the winter months, intensive shipping and difficulties protecting and securing net cages situated far from ports create additional challenges.

Open Cages – the predominant cultivation method

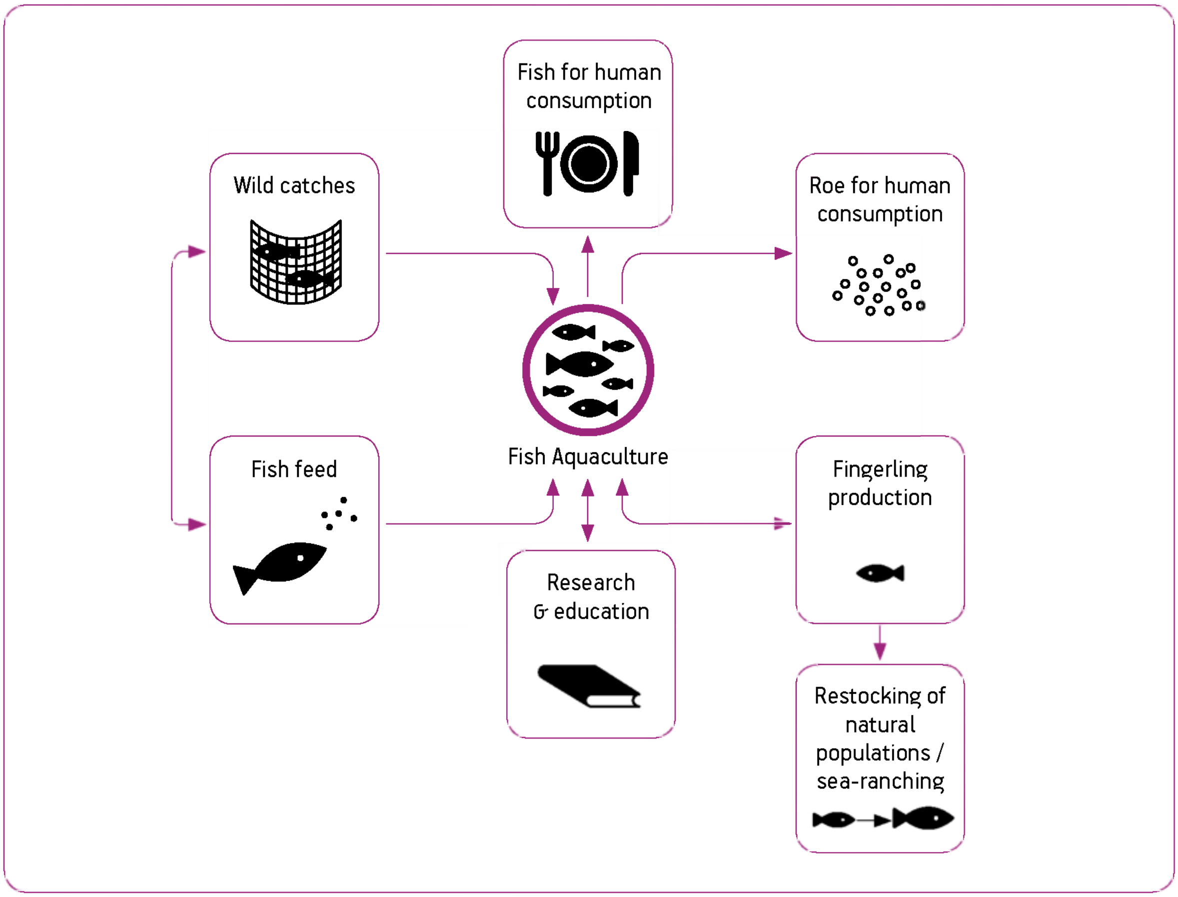
The predominant cultivation method used in the Baltic Sea Region is open net cage farming at sea for salmon trout cultivation. This method is used along the coastline of the north-western Baltic Sea, where large parts of the coast are protected by archipelagic islands. Other (more sustainable) methods already in use are land-based saltwater farms (ponds or tanks with water treatment measures) and seawater recirculation systems, also known as Recirculating Aquaculture Systems (RAS).

REGIONAL CASES

DENMARK: SHOWING THE PATH TO SUSTAINABLE PRODUCTION

Since the early 1900s, Denmark has been producing salmon and rainbow trout, originally farmed in freshwater ponds and later on in coastal net cages and land based marine aquaculture units. Strict environmental regulations introduced in the late 1980s including requirements for maximum annual feed allowances, restriction of water intake and maximum amounts of nutrients in outlet waters led to a downward trend in production and the closure of many fish farms. Certain fish farms, however, reacted to these new regulations by strengthening their water treatment practices. They have today developed into model fish farms that use recirculating and water treatment technologies and have increased production while keeping the amount of nutrients in effluent waters low. This trend has also led to the development of a successful niche market for the export of Danish recirculating aquaculture technology.

Figure 5: Applications of fish aquaculture and its interaction with various other practices and resources.



Applications

The World's Most Popular Source of Animal Protein

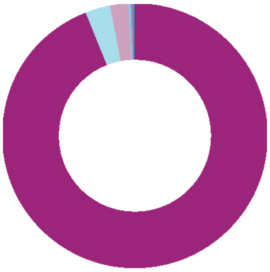
The main product derived from marine aquaculture is obviously farmed fish for human consumption in fresh, frozen or processed form and which can be marketed as whole fish, fillets or convenience products. It is generally accepted that fish is a healthy source of animal protein and its consumption in a well-balanced diet is recommended by the World Health Organisation. In particular, marine fish contain a high amount of omega-3 fatty acids with substantial benefits for heart health. By-products such as roe and fish oil are also sold and often have a high market value.

In the Baltic Sea Region, marine fish aquaculture production for human consumption is centred around a few key species, namely salmon trout (overwhelming majority of the volume produced) as well as some whitefish and in small quantities sea trout, Atlantic salmon, cod and turbot. An essential by-product of salmon and trout aquaculture is roe, which is marketed as 'salmonid caviar' for human consumption.

An Important Contribution to Restocking

In addition to products for direct human consumption, marine aquaculture within the Baltic Sea plays an important role in closing the reproduction cycle of farmed and wild fish, thus protecting natural fish stocks and preserving biodiversity. Fingerlings and fish hatchlings bred in hatcheries around the Baltic Sea Region are not only used directly in marine aquaculture farms but also for restocking and "sea ranching" purposes. In the latter cases, when the fish are old enough they are freed from the hatchery to mature in the open sea with the goal of improving natural fish stocks and consequently improving the return from capture fishery. Almost all Baltic Sea countries participate in restocking programmes,

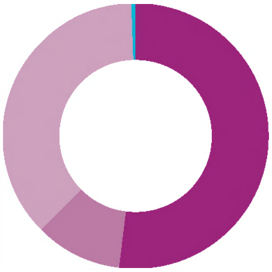
Figure 6: Marine aquaculture production in the Baltic Sea in 2009.



PRODUCTION IN TONNES	CULTIVATED SPECIES
● 23,078	Salmon trout
● 753	Roe for human consumption
● 578	Whitefish
● 64*	Turbot
● 37	Sea trout
● 15	Atlantic salmon
● 5**	Cod

* 2006, ** 2008

Figure 7: Overview of net cage production of salmon trout in Finland, Sweden, Denmark and Germany in 2009.



VOLUME IN TONNES	COUNTRY
● 10,000 t*	Finland
● 2,000 t	Sweden
● 7,100 t (a)*	Denmark
● 100 t	Germany

* Danish salmon trout production in net cages amounted about 10,000 t in 2009, of which 7,100 t can be attributed to Baltic Sea production (Sjælland county).

particularly for Atlantic salmon, sea trout, whitefish and turbot.

The contribution of fish aquaculture to restocking mainly depends on the cultured fish species and the aquaculture system used, its size and its intensity. Species that live naturally in large shoals can be held in high stocking density whereas the opposite may be said for territorial species. For salmon trout, the main produced species in the Baltic Sea, stocking densities up to 100 kg/m^3 are possible whereas the stocking density for the ongrowing of Atlantic salmon lies at about 20 kg/m^3. Even within one species the possible stocking density may vary depending on the stage of development and the used aquaculture system. Compared to the ongrowing of Atlantic salmon in net cages, intensive nursery systems for Atlantic salmon (e.g. RAS) can reach up to 50 kg/m^3.

REGIONAL CASES

AQUACULTURE CONTRIBUTIONS TO RESTOCKING

Finland

In 2010, the Finnish fish aquaculture sector produced about 65 million fish hatchlings for both further aquaculture rearing and for restocking. The production of different salmon and trout species amounted to about 29 million individuals of which 21 million rainbow trout fingerlings where exclusively produced for food fish production. From the remaining 8 million individuals (Baltic salmon, Landlocked salmon, Brown trout and Sea trout) 79 % where destined for stocking purposes. Of all 485 Finnish fish farms in 2010, 95 farms concentrated exclusively on fry fish production and over 200 farms operated in fry fish as well as food fish production.

Sweden

The Swedish contribution to restocking amounted in 2009 to about 2.8 million hatchlings which were released into rivers mostly running into the Baltic Sea. Of these 2.8 million, 0.7 million fry were sea trout and 2.1 million salmon.

Denmark

In 2009, Danish fish aquaculture farms released about 108 tonnes of fish juveniles and 8 tonnes of larger fish for restocking purposes. Of these, about 50 tonnes were produced in freshwater farms and 62 tonnes in re-circulating systems farms. The value of the released fish amounted to DKK 18.3 million (about € 2.5 million).

Competence Centres

Table 1: Overview on marine fish aquaculture related research institutes in the Baltic Sea Region.

Research institute	Research topics	Contact Person	Website
DTU Aqua, National Institute of Aquatic Resource, Technical University of Denmark	Aquaculture nutrition, growth and welfare, rearing systems and environmental effects	Senior Research Scientist Per Bovbjerg Pedersen	www.aqua.dtu.dk
Department of Marine Ecology, University of Gothenburg, Sweden	Oyster farming, algal toxins, mussel farming, small-scale aquaculture in developing countries	Aquaculture group leader Susanne Lindegarth	www.bioenv.gu.se/english
Finnish Environment Institute (SYKE), Finland	Interaction in coastal waters: a roadmap to sustainable integration of aquaculture and fisheries (COEXIST)	COEXIST project contact at SYKE Juha Grönroos	www.environment.fi
Finnish Game and Fisheries Research Institute (FGFRI), Helsinki, Finland	Promoting the aquaculture sector, developing the management of fisheries, selective fish breeding and development of aquaculture technology	Research manager Asmo Honkanen	www.rktl.fi/english
Chair of Hydrobiology, Faculty of Biology, University of Latvia	Creation and maintenance of aquaculture collection (organisms of phytoplankton, zooplankton, benthos and fish fauna), algae blooms and toxins	Head of Chair Assoc. Prof. Andris Andrusaitis	www.lu.lv/eng/faculties/fb/structural-units/chair-of-hydrobiology/
University of Kiel / Gesellschaft für Marine Aquakultur mbH, Büsum, Germany	Alternative fish feed, online-controlled culture systems, sustainable development of aquaculture, extractive aquaculture with mussels and algae in the Baltic Sea, water treatment		www.gma-buesum.de
Chair of Agriculture and Sea Ranching, faculty of Agricultural and Environmental Sciences, University of Rostock, GErmany	Environmental impact of marine aquaculture, fish culture technology, aquatic invertebrates as biological indicator for environmental changes and as diagnosis for aquatic parasites, live feed project	Head of Chair Prof. Dr. Harry Palm	www.auf-aq.uni-rostock.de
Institute of Ichthyobiology and Aquaculture Golysz, Polish Academy of Sciences	Fish culture technology, genetic optimization, environmental interaction		www.fish.com.pl/iia_index.html
Institute of Animal Science of the Estonian Agricultural University, Estonia	Genetics, selective breeding, fish farming technology, restocking, population ecology and fish health		vl.emu.ee/en/
Division of the Aquaculture and Inland Waters, Fisheries Services, Lithuania	Inland aquaculture	Head of Division Birutė Paliukėnaitė	www.zuv.lt

Technology

Globally there is a large spectrum of methods and systems for farming aquatic organisms, ranging from high-tech indoor systems and intensive marine net cage aquaculture to small family ponds and rice fields stocked with fish. The differences are mainly due to variations in the culture environment, location and production intensity as well as, of course, the type of species cultivated. In Asia, extensive pond cultures are the predominant aquaculture system, whereas Europe and North America focus on more intensive and often more technology demanding practices.

Increasing competition over coastal area use as well as environmental concerns about unsustainable practices have led to the development of a range of new and innovative methods and technologies in the aquaculture industry. These emerging systems are tied to the most advanced research and are continuously evolving towards a more sustainable development, ensuring the use of best environmental practices and best available techniques.

Open Water Net Cage Farms

A net cage is a type of enclosure culture unit and involves the holding of aquatic organisms within an enclosed space while a free water exchange is maintained. The cage normally consists of a floating frame, net or meshing materials and a mooring system. It can be placed on different positions within the water column (floating, submerged or submersible).

From a technological perspective, this type of culture system has the disadvantage of having to withstand variable environmental conditions including water temperature changes, ice cover, high waves, storms and changes in water quality such as toxic blooms or low oxygen levels. Thus only a very limited number of suitable sites exist throughout the Baltic Sea Region.

The most important disadvantage, however, are the environmental concerns relating to the pollution generated by the waste effluents as well as escapes and diseases from fish reared in net cages affecting natural fish populations.

Nevertheless open net cages are currently still the main aquaculture system used in the Baltic Sea Region. Available net cage technology and know-how have assured a low but stable production of fish over the past years. However, mainly the environmental concerns and the lack of suitable space have imposed a natural limit to this type of culture within the region.

New opportunities for the existing net cage aquaculture system may, however, arise from their combination with integrated systems, which decrease the environmental impacts (see IMTA paragraph and Environmental Assessment) or with offshore wind parks, reducing spatial competition and coastal impacts (see “Combinations with Offshore Wind Parks” chapter).

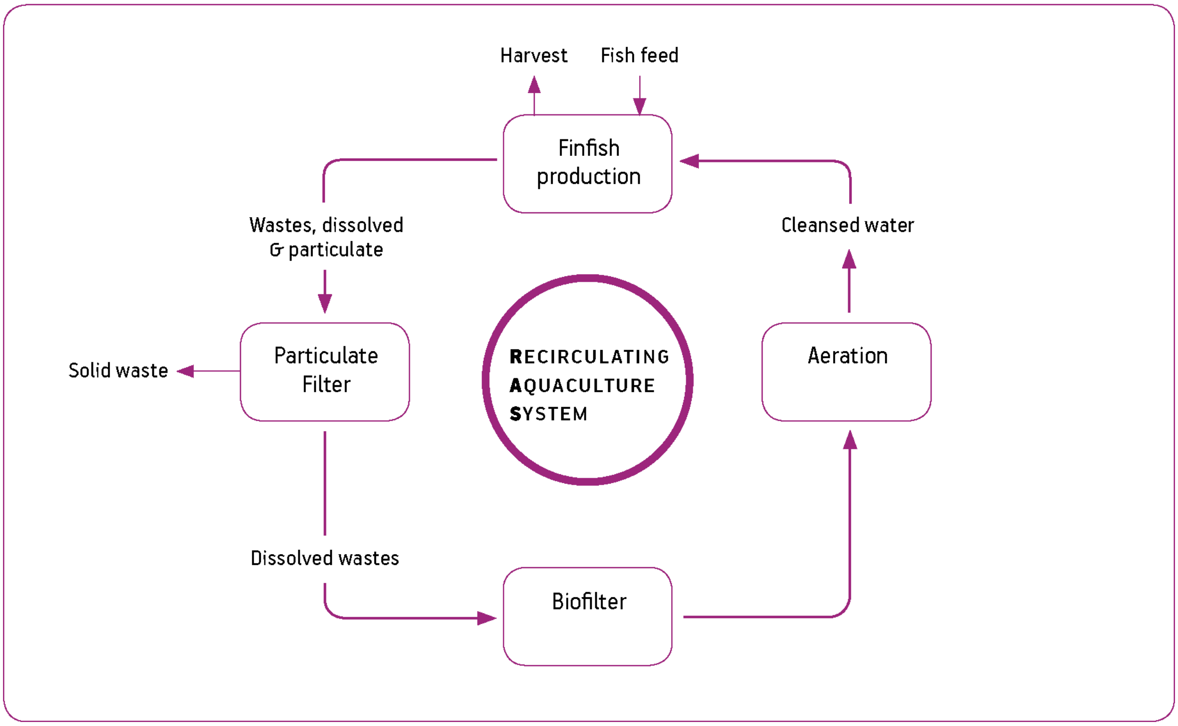
Recirculating Aquaculture Systems

Recirculating Aquaculture Systems (RAS) are land-based systems using freshwater or saltwater to cultivate fish and other aquatic species in tank and raceway systems. In comparison to traditional aquaculture systems such as open water net cages, modern recirculating systems can transform effluent wastes into non-harmful products with little or no effect on the cultured species. Through a combination of low water exchange rates and advanced mechanical and biological filtration technology, RAS recycle wastewater thus mitigating against waste effluent pollution while using comparatively low water. Modern systems with intensified recycling can even go down to 1–2 % daily water exchange rates.

Modern closed saltwater land-based systems could resolve the problem of coastal site selection as they do not depend on suitable coastal hydrological conditions and also provide the necessary regulation of water parameters.

The main weaknesses of RAS are the high operating costs in terms of energy use for water treatment, as well as high initial investment costs for

Figure 8: Schematic diagram of a Recirculating Aquaculture System (RAS).



plant construction. The use of alternative heating methods such as the combined use of biogas plants could reduce costs and ensure sustainability.

It furthermore takes a considerable amount of time to introduce a new species, as for instance high priced non-endemic fish species, as food product for domestic markets and gain consumer acceptance. In this case a suitable strategy must be established so that new marine fish aquaculture enterprises have a chance to establish aquaculture farms based on producing sea food otherwise imported from non EU countries.

In comparison to net cage farms offshore, RAS have multiple advantages, including the following:

- Effluent water, often containing high nutrient loads, can be treated before being discharged.
- Systems operate independently from seasonal influences and are thus able to produce seafood year round.
- They are isolated from most impacts on natural systems.
- They can be placed in areas where the use of net cages is not possible due to a lack of suitable sites.

However, due to high energy consumption for water circulation and treatment as well as high costs for establishment, the capital investment and operation costs of RAS are comparably high.

RAS are well suited for the production of juvenile fish as the environment needed for rearing can be adapted to the requirements of the individual fish species. The high water quality standards necessary for fry fish production can be assured by water quality control and monitoring mechanisms.

RAS in the Baltic Sea Region are currently mainly used as hatcheries for stock enhancement and restocking programs of endemic fish species. However, some commercial RAS for food fish production do exist in Germany and the Danish North Sea coast, and mostly produce high priced fish species such as turbot or Atlantic salmon in order to cover high investment costs.

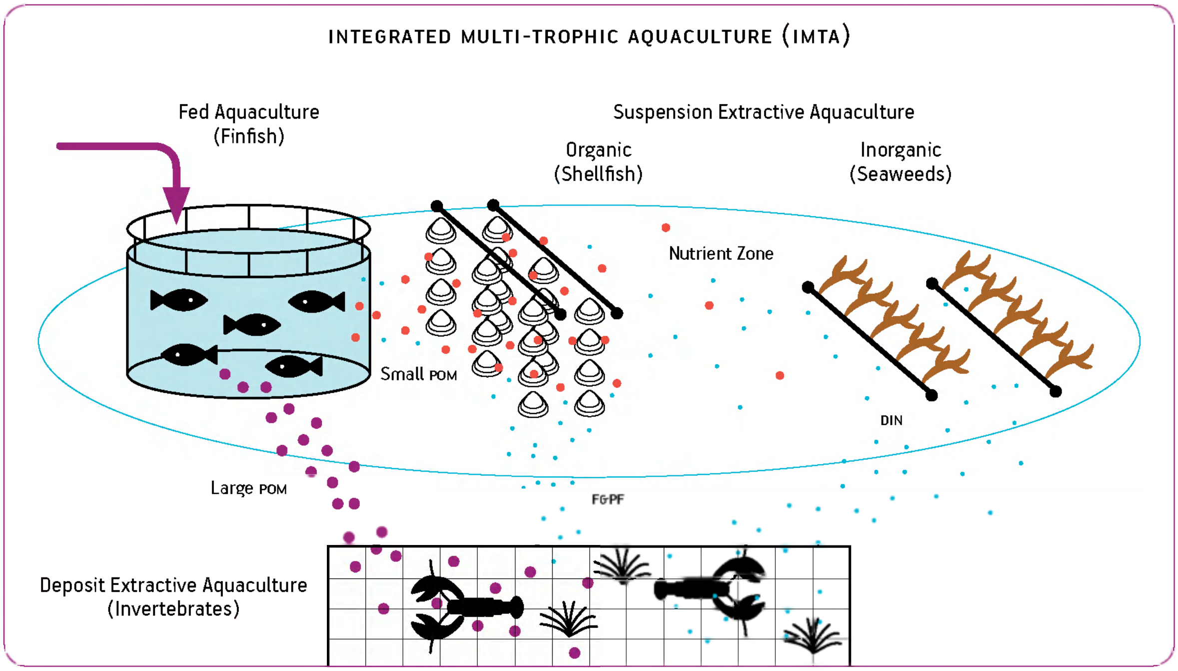
Figure 9: Land-based aquaculture installation in Pinnow, Germany.

Integrated Multi-Trophic Systems

Another system that has gone beyond the experimental scale is Integrated Multi-Trophic Aquaculture (IMTA), either in open water or land based systems. IMTA constitutes an advancement of traditional farming systems in its incorporation of species from different trophic positions or nutritional levels into the same system, so that each organism profits from the other. One example of IMTA is the combination of fish culture with macroalgae and invertebrate culture. Invertebrates and seaweeds filter and absorb the nutrients from the fish operations. Then, not only the cultured fish can be sold, but also the algae and mussels, which can be used as food for human consumption or as feed, fertilizers and for other applications. This method reduces the environmental impact of aquaculture and simultaneously increases profitability.

Adding variations of IMTA to existing near-shore open net cage systems can significantly reduce their environmental impact through the direct uptake of dissolved nutrients by primary producers (e.g. macroalgae) and particulate nutrients by filter feeders (e.g. mussels), and through harvesting, remove the nutrients from the location[4]. Furthermore, using the harvested mussel and macroalgae biomass for fish

Figure 10: Conceptual diagram of an Integrated Multi-Trophic Aquaculture (IMTA) system (based on Chopin, 2011[5]) (POM: particulate organic matter; DIN: dissolved inorganic nutrients; F&PF: faeces & pseudo faeces).



feed is an indirect reduction of the environmental pressure on wild stocks exploited for fish feed.

Worldwide, however, only a few countries have IMTA systems near a commercial scale like Canada, Chile, China and Scotland. In Southern Europe, France, Portugal and Spain have ongoing research projects related to IMTA. Some Scandinavian countries are making groundwork on this field, esp. Norway.

In order to promote the expansion of IMTA in the Baltic Sea Region more knowledge has to be generated on the selection of the right species appropriate to the habitat. Suitable species for IMTA in the Baltic Sea include blue mussel (*Mytilus edulis*) and zebra mussel (*Dreisena polymorpha*) as filter feeders and sea beech (*Delesseria sanguinea*) and sugar kelp (*Saccharina latissima*) as macroalgae components.

In a recent publication on IMTAs and their possibilities of expansion, the authors conclude that IMTA is the best option for a sustainable aquaculture industry: It is environmentally responsible, economically profitable and more socially acceptable than other systems[6].

Nevertheless it has to be noted that these systems are currently mainly in visionary stage for the Baltic Sea Region as numerous actions are still necessary in order to make the introduction of such technology interesting and feasible for commercial aquaculture companies:

- Implementing appropriate R&D projects
- Establishing the economic and environmental value of IMTA systems
- Selecting (native) species appropriate to the habitat and available technologies
- Selecting species according to the environmental conditions
- Promoting effective government legislation / regulations
- Commercialization of IMTA products

Environmental Assessment

There are a number of environmental problems generally associated with aquaculture development that need to be overcome in order to achieve sustainability. These include a negative impact on water quality arising from fish waste effluent, the interactions with natural populations and the larger ecosystem, and the use of unsustainable wild fish populations as the source of fish feed.

There is, however, the potential to minimise some of these environmental concerns through the use of innovative technologies, sustainable feed supply chains and the application of an ecosystem management approach. Recirculating Aquaculture Systems or the addition of Integrated Multi-Trophic Aquaculture to existing open net cages are examples of advancements in the field that can significantly reduce environmental impacts through water efficiencies, wastewater recycling and direct uptake of dissolved nutrients. However, existing knowledge gaps must first be overcome in order to successfully implement IMTA concepts with open net cage systems.

Water Quality

The nature and regimes of aquaculture feeding play a major role in determining the degree of environmental impact, particularly for open water net cage aquaculture production systems, where the use of compound fish feeds increases the environmental pollution resulting from waste effluents.[7, 8, 9, 10, 11, 12, 13] The bulk of dissolved and suspended inorganic and organic matter contained within the effluents is derived from feed inputs, either directly as the end-products of feed digestion or from uneaten feed,[14] or indirectly through eutrophication and increased natural productivity.[15] In general, the greater the intensity and scale of production, the greater the nutrient inputs required and the consequent risk of potential negative environmental impacts.

RAS and IMTA systems go a long way in minimising the impact of pollution from fish waste effluent compared with open water net cage systems.

Table 2: Overview of the different impacts of 4 aquaculture technologies on environmental objectives and priorities (i.e. Open Net Cage System (Open); land-based Recirculating Aquaculture Systems (RAS); near-shore Integrated Multi-Trophic Aquaculture (IMTA)).

Environmental Objective	Environmental Priority	Open	RAS	IMTA	Comments
Water quality	Bathing quality	🔴			
	Water transparency	🔴	🟠○	🟠○	
	Eutrophication	🔴	🟠○	🟠○	
	Biogeochemical cycles	🔴		🟠	Beneath the site
Habitat / Species protection	Food web dynamics	🔴		🟠	Phyto-zooplankton interactions
	Biodiversity	🔴	🟠	🟠	Benthos & anoxia
	Benthic habitats	🔴		🟠	Anoxia
	Bird habitats	🔴	🟠	🟠	Natural stocks used for feed
	Fisheries	🔴	🔴	🔴	Natural stocks used for feed
	Marine mammals	🟠	🟠	🟠	Natural stocks used for feed
	Marine noise				
Coastal protection	Coastal morphology				
	Scenery	🔴		🟠	Depends on setup
Climate protection	CO_2 Emissions		🔴		Are Aqua systems energy intensive?

🔵 strongly supportive
◍ moderately supportive
🔴 strongly not supportive
🟠 moderately not supportive

○ neutral
? gaps in information;
blank not applicable

However, caution should be exercised in adopting either of these systems as configuration, site selection and scale of operations are important factors in determining their effectiveness.

For RAS, the degree to which water is reused and the extent and characteristics of the water treatment processes used will directly relate to the impact of the treated effluent on the natural environment. Removal processes should include (at a minimum) aeration, oxygenation, solids removal and biofiltration with denitrification. Also, the polluting constituents removed from the effluent (e.g. dissolved and particulate organic matter, suspended solids, nitrogen, phosphorus) still have to be properly dealt with in terms of disposal.[13]

Habitat / Species Protection

Unfavourable benthic impacts are expected from the deployment of IMTAS as a result of rapidly sinking rates of feed and faecal pellets, and organic enrichment of the sediments due to increased sedimentation. Shading of the local ecosystem is expected and interactions with wild fish and predators are also likely as wild fish are attracted to cages due to food availability.[21] Furthermore, various chemicals and medicines are used in marine fish aquaculture which accumulate in the benthic organisms and sediments below the net cages.[24, 25] Little is know though on the sensitivity of benthic habitats to these environmental hazards and medicines. There is a need for local knowledge of the prevailing currents in order to assess the full impact on the benthos.

Overall, the use of wild fish stocks as a source of fish feed remains a major issue for all aquaculture technologies (see "Additional point"). Furthermore, these natural stocks may be contaminated by their natural environment and there is a further risk of transferring contaminants higher up the food chain. Providing an environmentally sustainable feed supply chain for aquaculture is key to realising sustainable fish aquaculture. The removal of large quantities of fish species from marine ecosystems has potentially ecosystem and biodiversity impacts on other dependent fish species, birds and mammals.

On balance, global aquaculture production still adds to world fish demand. The future challenge for a further successful development of the aquaculture will be to minimize the natural fish supplies for feed (Natura 2000).

ADDITIONAL POINT

Feeding the Fish

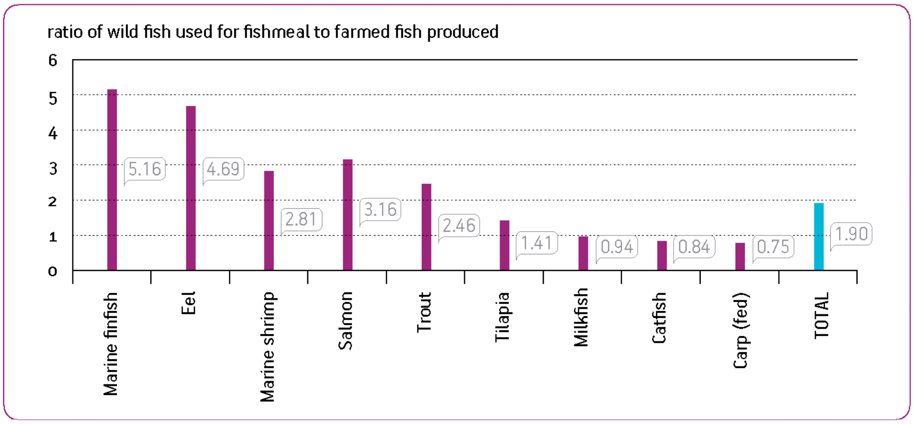
Carnivorous or omnivorous fish raised in an aquaculture systems need to consume nutrients from other fish and seafood, just as in their natural habitat. These nutrients are obtained from small wild-caught fish (e.g. anchovies) that are processed into fishmeal or fish oil. Consequently, aquaculture is the largest overall user of fishmeal and fish oil, currently accounting for around 56 % of global use[16] and over 50 % of European use,[17] particularly in the salmon and trout industries. As a result, one of the major challenges facing sustainable aquaculture development is the procurement of feed for non-herbivorous fish from sustainable sources. To put this into context, it takes more fish biomass to raise some farmed species than those species actually produce.[18]

Projections concerning the future availability, price and use of fishmeal and fish oil vary widely, with some expecting their use to decrease in the long term as a result of rising prices due to limited supplies and increased demand, while others, in particular those of the International Fishmeal and Fish Oil Organisation (IFFO), project fishmeal and fish oil use to steadily increase. Already in 2012, aquaculture is projected to use 60 % of the global supply of fishmeal and 88 % of the global supply of fish oil.[20] Nevertheless, the maximum possible yield of fishmeal and fish oil from natural populations is expected to cap at 45 to 50 million metric tonnes per year, a level that at current growth rates of global marine food production will be reached by 2040.[21]

Given the combination of the rising cost of fishmeal, the growing demand for a finite resource and the growing concern over the "food miles" involved in transporting fishmeal around the world,[22] feed suppliers have focused on the potential to substitute fishmeal and fish oil with plant-based alternatives. However, the level of substitution possible is restricted by their lack of some essential amino acids which may limit growth. There are also concerns related to the sustainability of using plant-based alternatives for feed as it is dependent on agriculture and raises issues related to freshwater availability and land use (i.e. more clearance of rainforests). In the SUBMARINER project, harvested blue and zebra mussels as well as macroalgae biomass, all cultured primarily for nutrient recycling and water quality improvement purposes, are being additionally explored as alternative ingredient sources for fish food.

It is clear that there are a number of obstacles that must be overcome if the feed supply chain is to become more sustainable. The food required to feed marine animals should be produced by marine aquaculture rather than harvested from the wild or derived from agriculture, thus closing the production cycle.

Figure 11: Ratio of wild fish inputs used in feed to farmed fish produced for ten types of fish and shellfish most commonly farmed in 1997. Based on Naylor et al., 2001.[19]



Climate Protection

Current operational requirements of an RAS are not carbon neutral. Both high energy consumption and water use are associated with establishing and running a RAS.

Socioeconomic Aspects

The total aquaculture production of the Baltic Sea Region countries including freshwater and marine species was worth € 370 million in 2007. The production based alone on saltwater environments in the Baltic Sea was estimated to be worth € 77 million in the same time period.

The most important factors affecting economic performance of the Baltic Sea Region's marine aquaculture sector are

- Heavy global competition with imports of farmed and wild caught species from other parts of the world;
- Strong demand for high quality and high value fish in Europe;
- Increasing costs of fish meal and fish oil for fish feed;

- Access to sites, licences and waste disposal; and
- Further development and implementation of innovative farming practises and technology to increase sustainability and decrease production costs.

Sustainability – a cost driver?

Even though economic considerations vary by type of system and intensity of production, most modern farms have in common that they are capital intensive businesses. The capital costs of an aquaculture business are mainly composed of the physical structures, but also costs of licenses, permits and legal costs involved in starting up a new business.

Compared to open water net cage farms, land based recirculating systems are not only more complex in their construction but can also require considerably more capital investment. Apart from the costs for physical structures required to operate tanks and water treatment, costs for land and buildings must be taken into account. For comparison: A **salmon net cage farm** in Norway, including a physical structure with a handling capacity of 1 million juvenile fish (biomass weight of 4,738 tonnes after a 16 month growth phase) corresponds to an approximate **€ 2 million** investment (including net cages, mooring, feed barge, storage, monitoring and feeding systems). An **Atlantic Salmon RAS** in Denmark with state of the art technology for 1,000 tonnes (with potential to expand production) is equivalent to a **€ 6.78 million** investment.

Also with regard to operating costs, which generally often exceed capital costs in the fish aquaculture sector, RAS systems are more expensive to run than net cage farms, because closed systems have higher energy costs to cover water circulation, water treatment and heating or cooling elements.

Fish feed often represents over 50 % of the fish farmer's production costs, even though fish have favourable feed conversion ratios compared to other domesticized animals. These costs are continuing to rise due to limited natural resources and rising commodity prices for fishmeal and fish oil. In general, production costs can be lowered through better use of feed, efficient feeding systems and vaccination of juvenile fish in open systems.

Most fish species do not reach market size in one season, meaning that aquaculture businesses must be able to endure a time period of no or low income until full production capacity is reached. If

Table 3: Capital and operating costs of open water net cage and land based RAS.

	Open Water Net Cage Aquaculture	**Land Based Recirculating Aquaculture System**
Capital investments	Net cages, mooring, harvesting equipment and feed barge, storing, grading and sorting equipment, protection against theft, feeding equipment, monitoring system licenses	Land, building, indoor drain, plumbing, effluent system, heating/cooling system, pumps, grow-out tank, reservoir tank, particle filter, biofilter, protein skimmer, oxygen incorporation, piping, feed storage, feeding system, harvesting equipment, water quality control equipment, monitoring and alarm system, backup generator, emergency oxygen system, licenses
Operating costs	Fingerlings, feed, mortality removal, disease treatment, net repair / replacement, predator control, harvesting, water quality control, maintenance, labour, management, operating fees	Fingerlings, feed, mortality removal, disease treatment, harvesting, water quality control, maintenance, water costs, sewage removal, oxygen price, electricity, labour, management, operating fees

production can be carried out as planned, four years must typically be allowed to reach full production capacity.

To reduce production costs and increase profitability, modern RAS businesses are advised to achieve a relatively high output with a minimum annual production capacity of at least 500–1,000 tonnes.[24] Furthermore, high operating costs have to be compensated by the production of high value fish species.

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

While RASs offer a more environmentally attractive solution to sustainable fish aquaculture compared to traditional open net cage systems, they are much more expensive to run. Adding IMTA solutions to existing net cages potentially offers a more cost-effective, environmentally sustainable solution as for almost the same costs, more products (e.g. mussels and algae) can be produced and sold.

ADDITIONAL POINT

THE “ECONOMICS” OF RESTOCKING

Generally the economics between aquaculture farms specialized on fish for human consumption or farms dedicated to restocking purposes differ not so much on the cost site but in the way prices are established for their products. Whereas the former have to calculate with normal consumer market prices, the latter depend on related government programmes, which pay for the environmental service provided by releasing hatchlings / juvenile fish to open waters.

As most of the costs depend on the location and the cultured species, naturally individual prices vary between the different countries within the Baltic Sea Region and no overall statement can be made to quantify the individual cost of fish production for restocking purposes.

Table 4: Production costs by category for juvenile salmon producers in Norway (2008).[27]

	Cost per juvenile (€)	Cost share (%)
Roe and fry	0.12	14
Feed	0.11	13
Insurance	0.01	1
Vaccination	0.15	18
Wages	0.16	19
Depreciation	0.06	7
Other operating costs	0.21	25
Net financial costs	0.03	3
Total costs	0.85	100

Employment

The EU aquaculture sector (both marine and freshwater) is estimated to generate approximately 65,000 direct full-time jobs[28] through mostly small and medium-sized aquaculture enterprises. In the Baltic Sea Region, the marine aquaculture subsector accounts for roughly 300 marine aquaculture enterprises (mainly small and medium-sized) with a total of 3,500 positions in part-time, full-time or seasonal jobs.

Modern aquaculture businesses in Europe often have highly automated operating processes, reducing the amount of employees directly involved in the production cycle while enhancing efficiency. Modern marine net cage farms often operate with 3–4 full time workers at each site including one manager. In closed systems the fish production per worker ratio can be even higher involving only one worker and one manager per facility. The indirect job creation in the fish processing and distribution sector is, however, likely to be considerably higher.

Marine aquaculture also plays an important role in wealth creation and contributes to regional development in otherwise economically deprived rural areas, where only a few alternative economic activities have been able to provide stable, long-term jobs.

Political Strategies

EU Strategies and Research Funding for Sustainable Aquaculture

The development of a more competitive and environmentally-friendly aquaculture industry is a major focus of European funding, both through the European Fisheries Fund (EFF) and EU research programs. In 2009, the Commission proposed a strategy[29] to give new impetus to the sustainable development of European aquaculture. The strategy focuses on three key elements: 1) promoting competitiveness of EU aquaculture production, 2) establishing conditions for sustainable growth of aquaculture, and 3) improving the sector's image and governance. The EU aquaculture sector aims at being at the forefront of sustainable development, supported by advanced research and innovative technology.

The European Union itself is also a key contributor to research and technological development in aquaculture. € 98 million were allocated to research projects for aquaculture under the 6th Research Framework Program. In the 7th Research Framework Program, € 124 million are contributing to fund projects which are either directly or indirectly related to aquaculture, of which about one third (€ 27.7 million) concern environmental issues. Focus is placed on the development of sustainable and ecofriendly aquaculture.

With the beginning of 2014, the new financing period of the EU will start with the establishment of new European Maritime and Fisheries Fund (EMFF). The Fund shall help to deliver the ambitious objectives of the reform of the Common Fisheries Policy and will help fishermen in the transition towards sustainable fishing, as well as coastal communities in the diversification of their economies. "Smart, green aquaculture" will become one thematic topic ("pillar") with the EMFF striving to boost this industry in a sustainable manner, rewarding innovation and promoting also new strands of aquaculture, such as non-food aquaculture.

Baltic Sea Region Strategies

Also Baltic Sea specific transnational and national strategies stress the necessity for a sustainable development of the aquaculture sector in the region and recognise its potential to play a key role in providing high quality and healthy seafood to consumers. To promote the sector, adequate framework conditions should be created and administrative burdens reduced. A main focus lies on further research and implementation of environmental friendly technology and compliance with best environmental practices. Table 5 gives an overview of the declarations, strategies and projects in place in

Table 5: Overview of declarations, strategies and projects in place in the Baltic Sea Region that seek to promote aquaculture at a national or regional level.

Baltic Sea-wide Declarations, Strategies and Projects

- EU Baltic Sea Region Strategy: Improvement of management of Baltic Sea resources; introduction of best available technologies and practices in the field of advanced technologies of mariculture
- Helsinki Declaration on Competitive and Sustainable Aquaculture in the Baltic Region, Aquaculture Forum, Helsinki, Oct. 6th 2011
- HELCOM Recommendation 25/4 on limiting the pollution from fish farms to the Baltic Sea by using Best Available Techniques (BAT) and Best Environmental Practice (BEP). Both RAS and IMTA systems comply with the requirements of BAT and BEP.
- Baltic Sea Region Programme Flagship project AQUABEST – Innovative practices and technologies for developing sustainable aquaculture in the Baltic Sea Region
- Baltic Sea Region Programme AQUAFIMA project – Integrating aquaculture and fisheries management towards a sustainable regional development in the Baltic Sea Region

National and Regional Declarations and Strategies

- **Sweden** – *Det växande vattenbrukslandet*: Aquaculture nation in the making, a national action plan
- **Denmark** – *Anbefalinger til en bæredygtig udvikling af dansk akvakultur*: Recommendations to the sustainable development of Danish aquaculture, main Report by the Government's aquaculture committee of 2009
- **Poland** – Programu Operacyjnego "Zrównoważony rozwój sektora rybołówstwa i nadbrzeżnych obszarów rybackich na lata 2007-2013": Balanced development of the Fishery sector and coastal fishery regions for 2007 – 2013
- **Latvia** – Sustainable Development Strategy of Latvia until 2030

the Baltic Sea Region that seek to promote aquaculture at a national or regional level.

Legal Aspects

Legal considerations within the aquaculture sector differ substantially from those of normal fisheries, since, in contrast to fishermen who do not take property until hauling, in aquaculture the aquatic organisms are the property of the operator at all times.

It is difficult to give an overview of legal aspects involved in the aquaculture industry, as these are highly dependent on where the facility is planned, which system is planned and which aquatic organisms shall be engaged. Also of importance is whether a facility has a direct output of effluent waters into natural water bodies or if they are directed into sewage systems.

Different rules exist for farms on land-based sites or for farms situated directly at sea, i.e. in coastal waters and the Exclusive Economic Zone (EEZ). Generally, however, coastal states also have the exclusive right to authorize and regulate the construction and operation of marine aquaculture installations within the Exclusive Economic Zone (EEZ), as this is regulated by the legislation of the coastal states adopted by the *United Nations Convention on the Law of the Sea*.

Essential in any case is the assessment / legitimacy of the planned operation against the background of site-specific environmental impacts and stakeholder objections both regulated at national and regional levels as well as relevant environmental EU-wide directives.

The extent and form of legal requirements for an aquaculture establishment differs substantially between the various Baltic countries and regions. Nevertheless the following sample list provides an impression of some of the legal aspects and regulations that must be taken into account:

- The Water Framework Directive (2000/60/EC) also pertains to aquaculture since it addresses the area extending up to one sea mile seawards from the coastline. Article 1 requires the enhancement of the status of aquatic ecosystems and Article 4 aims to prevent deterioration of all bodies of surface water.
- The area further seawards is then covered by the Marine Strategy Framework Directive (2008/56/EC), which also lists mariculture in Annex III Table 2 "Pressure and impacts" under "Nutrient and organic matter enrichment", for which contracting parties are obliged to achieve good environmental status.
- Art. 8 lit. h of the Convention on Biological Diversity as well as EU Council Regulation (EC) No 708/2007 require the control of any alien species with might threaten the ecosystem and apply to aquaculture operators.
- Also an assessment according to Art. 6 para. 3 of the Habitats Directive (92/43/EEC) may be needed. According to this provision, any plan or project likely to have a significant effect on a protected site under Natura 2000 shall be subject to appropriate assessment.
- In Germany the Federal Act on Environmental Impact Assessment (EIA) requires in any case that intensive fish farming plans conduct an EIA.
- Overall the dumping of substances represents a fact of use ("Benutzungstatbestand") according to the Water Management Act (§9 para. 1 no. 4) in Germany, which requires a special permission (§ 8 para. 1).

Table 6: Responsible authorities for mariculture establishments in the Baltic Sea Region countries.

Country	**Responsible authority for licenses, permits and control of mariculture establishments**
Germany	Federal state water authorities (mariculture in coastal waters) Federal Maritime and Hydrography Agency (mariculture in the EEZ)
Sweden	Board of Fisheries and the Board of Agriculture Local administration and licenses issued by County Administrative Boards (occasionally in combination with the Water Rights Court)
Finland	Regional Environmental Permit Authorities
Denmark	Directorate of Fisheries (Application approval by the Danish Coastal Authority, Ministry of the Environment, Danish Veterinary and Food Administration, Danish Maritime Safety Administration, Danish Institute for Fisheries Research, Danish Fishermen's Association)
Estonia	The Fishing Industry Department, Ministry of Agriculture (freshwater aquaculture)
Latvia	National Board of Fisheries of the Ministry of Agriculture (freshwater aquaculture)
Lithuania	Federal administrations of the Minister of Agriculture and the Minister of the Environment regulate the establishment of new aquaculture activities. Licenses are not necessary (freshwater aquaculture).
Poland	Ministry of Agriculture and Rural Development, Department of Fisheries and local authorities (freshwater aquaculture)

ADDITIONAL POINT

LABELLING AND CERTIFICATION

Labelling and certification are important parameters in a product strategy, especially when entering international trade. In 2002 the EU introduced new labelling requirements for fishery products specifying that all products shall carry labels that state among others the production method (capture or farmed), catch area of wild species (FAO fishing area) and the country of production in the case of farmed fish products.[30]

The usefulness of eco-labelling in creating a market-based incentive for environment-friendly production was recognized about two decades ago when the first eco-labelled products were put on sale in Germany in the late 1970s. Since then, and especially during the 1990s, eco-labelling schemes have been developed in most industrialized countries for a wide range of products and sectors

In order to promote sustainable aquaculture practices and maintain market shares in eco-sensitive export markets, the aquaculture industry is developing eco-labelling schemes for those products, which are deemed to have fewer impacts on the environment than functionally or competitively similar products. The so-called "Aquaculture Stewardship Council" shall act as the correspondent label to the currently widely spread "Marine Stewardship Council / MSC" for sustainable fishery.

Eco-labelling criteria are for instance the amount of fishmeal as well as fish density in ponds. Whereas these efforts apply to net cage systems, EU regulation No 710/2009 article 25G on organic aquaculture animal and seaweed production, currently still prohibits closed recirculation aquaculture animal production facilities (i.e RAS) from such eco-labelling schemes in view of non-sufficient space and animal wellbeing.[31]

SWOT Analysis

GENERAL SWOT

STRENGTHS

- Provision of high quality and healthy seafood for human consumption not affecting natural fish stock populations
- Growth in development of new systems with decreased impact on the environment
- Contribution to the well-being of coastal regions
- Facilitation of structural transformation from fisheries to aquaculture without losing jobs
- Creation and strengthening of a domestic market and reduction of import reliance
- Contribution to protection of natural fish stocks and reduction of environmental impacts
- Environmentally friendly activity in terms of reduction of transport needs and CO_2 emissions
- Availability of qualified employees (well developed university and training courses)

WEAKNESSES

- Lack of good practices (few farms are running on a commercial basis to provide examples)
- Hardly any tradition of marine aquaculture in the Baltic Sea Region
- No well-functioning processing chain for aquaculture products
- Fish feed still largely dependent on fish meal from capture fisheries
- Long time to reach full production capacity (ca 4 years) due to fish growth rates

OPPORTUNITIES

- Growing demand for food
- Growing demand for high quality seafood in Baltic Sea Region countries
- Growing demand for Baltic Sea Region brand products
- World fish capture production expected to stay stagnant
- Declining fish stocks due to overfishing
- Global development of the aquaculture sector, especially in the high quality/price sector
- EU support in form of Integrated Maritime Policy and structural funds
- Combination with other marine uses may improve financial viability
- Growing development of high-technology
- Global drive towards sustainable development

THREATS

- Low public acceptance for locally produced aquaculture products (too little public awareness)
- No enough political support
- No investment and financial support due to the actual economic and financial crisis
- Competition from other countries producing cheaper products and having longer experience
- Continuously rising prices of fish meal
- Worsening Baltic hydro-meteorological conditions due to climate change
- Potentially increasing nature protection requirements
- Low quality standards and regulations for fish cultureas well as water treatment in many non-EU-countries

RECIRCULATING AQUACULTURE SYSTEMS

STRENGTHS	WEAKNESSES
• Environmentally friendly and sustainable food production • Already existing technology, know-how and a variety of companies for plant construction and operation of closed RAS • Easy to combine with other uses such as biogas plants • Low land and water requirements • All-year constant seafood production possible • High safety standards applicable • Good substitute to "traditional" mariculture where the latter one is impossible due to lack of suitable places	• Few new RAS start-ups • Highly experienced employees necessary to run RAS • High running costs in terms of electricity and water use as well as high investment costs for plant construction • Long process for new fish species to be reared in RAS to achieve market appeal • Limited possibility of water use and discharge due to strict regulations • No eco-certification
OPPORTUNITIES	**THREATS**
• Expanding technological progress • Combination with other uses such as biogas plants as heating source and use of waste water for greenhouses improves financial viability and environmental standards • Support from the side of environmentalists and politicians	• No local and public support for building new RAS plants • capital investment relatively high because of the technical components • Well trained employees are obligatory

OPEN WATER NET CAGE AQUACULTURE WITH IMTA

STRENGTHS	WEAKNESSES
• Highly developed technology and know-how for open net cages • With IMTAs even more cost-efficiencies due to more products which can be sold • Automatized feeding, monitoring and harvesting processes potentially reducing production costs • Ease of combination with other uses (e.g. offshore wind farms), increasing profitability and optimising sea area use • Potentially eco-certified.	• Only limited areas with suitable coastal morphology and water parameters • Also with IMTA still possible negative impacts on the ecosystem due to pollution and especially escapes and diseases which may affect natural fish populations • Fish growth limited to warm seasons • Sensitivity to ice drifts • Very limited practical knowledge on IMTAs and lack of related research / pilot sites

OPPORTUNITIES	THREATS
- Technical progress allowing development of existing net cages farms towards a sustainable IMTA approach - Further development of offshore wind energy in the Baltic Sea Region offering increased opportunities for combination of space use.	- No licences for new marine aquaculture start-ups in general - Long term effects / impacts of integrated systems unknown - Opposing stakeholder interests

Knowledge Gaps

There is little experience with RAS and IMTA technology in the Baltic Sea Region and the long term impact of deploying these systems is unknown. Further research would be beneficial in a number of areas.

These include:

- Improving water treatment techniques
- Developing sustainable feed supply chain
- Improving feeds so that higher nutrient fractions are retained by the fish
- Applying carbon neutral alternative energy sources to meet high energy demands of running RAS
- Selection of species appropriate to habitats, environmental conditions and available technology
- Economic feasibility studies of IMTAS
- Monitoring the efficiency of nutrient uptake by IMTA systems
- Combining marine fish aquaculture with other marine uses to improve its financial viability
- Potential sites for open and/or closed systems in the Baltic Sea Region

Conclusions

The main opportunities of a growing, well organized and ecologically sound marine aquaculture sector in the Baltic Sea Region lie mainly in the growing desire for regional and environmentally friendly marine food products as a substitute for fish / fish aquaculture imports from overseas. The Baltic Sea Region countries have a well-functioning technology sector on which aquaculture companies can rely on to plan, construct and operate aquaculture systems which are technologically advanced and thus more environmentally friendly.

However, the main weakness of the current marine aquaculture sector in the Baltic Sea Region, compared to that of other regions, is that there are only few successfully operating marine aquaculture companies, especially ones which are using modern environmentally friendly technology, to take as example for future start-ups.

The implementation of innovative aquaculture systems such as RAS, IMTA and other combined uses must therefore be carefully examined for each country and region individually. Countries which already have marine aquaculture activity, mainly in form of nearshore net cage farms, might choose to strengthen their industry by using the advantages of existing infrastructure and introducing innovative technology such as IMTA to already existing farms. In addition, new emerging systems such as RAS could be established were suitable coastal sites are already in use. Countries where marine aquaculture is not yet establish due to a lack of suitable nearshore sites as well as other reasons, might seek to introduce aquaculture systems that are land-based.

Additional importance lies on the necessity to create public awareness and ultimately public acceptance for sea food produced in marine aquaculture in the Baltic Sea Region. When planning the development of the mariculture sector and eventually building new facilities all stakeholder interests must also be taken into consideration. The sectors with high conflict potential are tourism, fisheries, shipping and nature conservation. Detailed communication and establishing agreements between different stakeholder groups during the planning process may avoid problems in the long run.

Generally the findings of the SWOT analysis on the further development of the marine aquaculture sector in the Baltic Sea Region – if conducted in a sustainable way – can be summarised as follows:

1. A sustainable development of the marine aquaculture sector in the Baltic Sea Region could have several positive economic (local food fish production), socioeconomic (job creation) and environmental (fish stock enhancement) advantages.
2. A suitable strategy for the sustainable development of the Baltic Sea Region marine aquaculture sector must be developed in coherence with the individual environmental conditions and legal characteristics of each country and region.
3. The use of environmentally friendly seawater Recirculating Aquaculture Systems could contribute to the sustainable development of the Baltic Sea Region marine aquaculture sector.
4. Already established marine net cage farms could extend their systems by using an integrative approach (IMTA), thereby reducing environmental impacts.
5. Offshore wind farms provide a possible opportunity for a combined use with marine aquaculture farms. Other viable combinations are also desirable.

Recommendations

Special strategies must be developed to pursue the opportunities identified, avert threats and eliminate weaknesses by using the strengths that would arise from a well-developed ecologically sound marine aquaculture sector:

- A positive example of a financially viable and sustainable aquaculture company in the Baltic Sea Region should be created as reference for future start-ups, facilitating financial help and attracting investment
- Production of a "Baltic Sea Region brand" for high quality and high value marine aquaculture products should be supported to avoid competition with established aquaculture sectors around the world
- Public awareness should be strengthened for locally produced endemic species instead of exotic species that require long distance transport
- The domestic market should be strengthened, resulting in less reliance on fish imports, food security and a decrease of transport emissions
- A local market for products should be created and regional producer groups should be established to boost the marketing of new species, simplify sales structures and reduce costs
- Promote new fish species for consumer markets.
- Proper education should be available to avoid a shortage of trained personal
- Research in the areas of water treatment, feed supply and efficiency, environmental impacts, should be supported.

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Combinations with Offshore Wind Parks

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THE EARLIEST REFERENCES ON THE POTENTIAL OF COMBINING fixed offshore installations with marine aquaculture emerged some 10–15 years ago in the US with suggestions for using old oil platforms for other purposes, possibly due to high costs of deconstruction. More recently, the concept has been proposed to combine wind power parks and mariculture facilities in order to improve the use of limited space at sea.

New sites through smart combinations?

Introduction

One of the limiting factors to new forms of using marine resources is the availability of suitable sites where cultivation or farming facilities may be installed. The so-called "spatial efficiency" principle postulates that sea space is a valuable public good and that the sea is no repository for problematic land uses. Thus space should be used sparingly: uses should be concentrated as much as possible to keep other areas free and co-uses, synergies and multiple spatial use should be promoted. Spatial scarcity is not only a technical issue but also depends on social perception, which suggest that it is easier to add a new use to an already "used" area rather than breaking into or disturbing a so far unused space.

The "spatial efficiency" concept is already an integral part of the German Maritime Spatial Planning Law. With maritime spatial planning becoming more and more of a reality it is expected that the principle of "spatial efficiency" will also become common rule in other countries.[1]

Even though this principle holds true for all sea areas throughout the world, the case for spatial limitations is especially dramatic in the Baltic Sea Region, where coastal and near shore areas host a highly competitive group of uses, including shipping (trade or private), sand extraction or disposal, military practice as well as areas which are sectioned off for specific purposes such as pipelines, cables, wind farms, nature reserves and other marine and coastal protected areas. Recreational activities as well as commercial fisheries and mariculture are additional interests.[2] In view of this highly competitive group of uses, it is difficult to find suitable places for aquaculture in the Baltic Sea Region. Combinations with offshore windmill parks may thus be an option to be considered.

A large number of offshore wind farms are already in operation, particularly in the Danish EEZ of the Baltic Sea. More are planned or under construction in most of the Baltic EU member states. Their increasing number, volume and spatial placement call for multiple use concepts that shall reap additional benefits from these areas.

As is now well known, aquaculture offers the potential to provide an additional source of food, feed and bioenergy. In addition, some aquaculture systems (e.g. algae, mussels) may simultaneously provide services like removing from the water nutrients coming from agricultural runoffs, wastewater and sewage treatment. From an economic point of view, synergistic effects may arise from the multiple use of existing installations and land-sea connections and maintenance requirements may be reduced. Furthermore, marine wind parks are often placed in low depth areas, which have served as traditional fishing areas. Mariculture in these areas could be a way to compensate for losses in the traditional fishery.

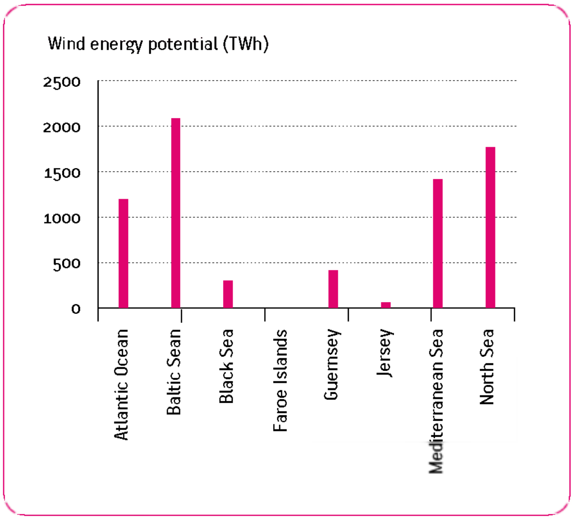
Offshore Wind Parks in the Baltic Sea Region

Technical Potential

Wind energy potential in the offshore Baltic is substantial: the unrestricted technical potential is estimated by the European Environment Agency (EEA) to exceed 2000 TWh per year, making this the region with the highest technical potential[2] in the EU (assuming the potential area for offshore wind energy generation is limited to depths less than 50 m).

The Baltic Sea offers better conditions in comparison with other areas such as the North Sea, where conditions are much harsher (high salinity, extreme wind and waves, deep waters, long distance to shore, tricky accessibility), which makes offshore wind energy more expensive in this area. In the Baltic Sea, less advanced technology is needed due to the milder conditions and the easier access to the sites, resulting in cheaper maintenance costs due to better all-year-round accessibility. These conditions translate into clear economic advantages: investment costs in the Baltic Sea Region are approximately € 1.2 million per MW compared to approximately € 2.7 million per MW elsewhere.

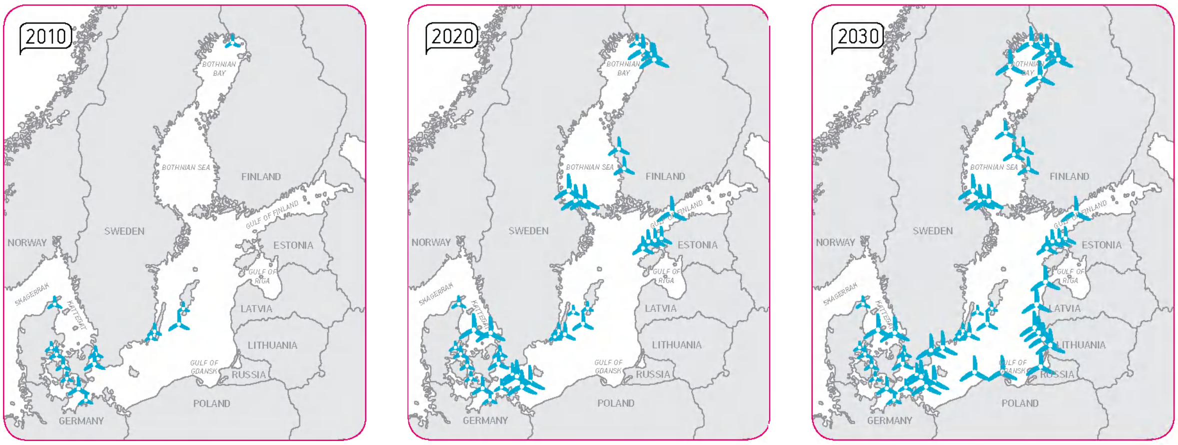
Figure 1: Unrestricted technical offshore wind potential 10–30 kilometres from the coast.[3]



Limiting Factors

However, theoretical technical potential for offshore wind does not take into account the fact that other given or projected uses of the sea areas (such as shipping routes, boat traffic, fisheries, military use, cables, oil extraction and other human activities) may limit the potential for offshore wind developments.

Figure 2: Outline of the present, planned and projected wind mill farms in the Baltic Sea area. (Data from WWF).



Spatial planning policies are then required to guide the proper use of the available sea areas. Relatively new utilisations of the sea, such as wind farms, are an integral part of any maritime spatial planning policy. In the Netherlands, United Kingdom and Poland for example, spatial planning measures require that wind farms be build at least 12 nautical miles away from the coast (about 22 km), mainly due to their visual impact.[3]

In light of these considerations, it is assumed that in practice only 4 % of the offshore area within 0–10 km from land might be available for development of wind farms and 10 % of the areas 10–30 km and 30–50 km from the coast.[2] For areas with a distance from the coast above 50 km, a larger share could be utilised because this area is relatively large and other functions such as shipping are less concentrated. Therefore it is assumed that 25 % of the areas above 50 km may be used for wind farms.

If these restrictions are applied, the unrestricted technical potential for offshore wind drops by a factor of ten in Europe (and probably even more in the Baltic Sea due to lack of suitable sites). However, the resulting amount of electricity from offshore wind would still be sufficient to fulfil about 78 % of the projected electricity demand in Europe in 2030 (5,100 TWh).[2]

Current Projections

In the Baltic Sea Region, the predicted increase in energy production from offshore windmill parks in coming years is substantial The predicted amount of electric energy in MW produced by offshore wind parks in the Baltic Sea Region in 2030 is estimated to 25,000 MW, with the number of wind farms estimated at 65 to 70. Though most Baltic States are working on planning and legal implementation of wind parks in the region, no comprehensive mapping of existing or planned wind power parks in the Baltic Sea Region has been done to date.

Table 1: Number of Baltic Sea offshore wind farms and electricity production capacities (in MW) in 2010 and predicted numbers for 2020 and 2030. Data from HELCOM and WWF.[2, 4]

	2010	2020	2030
Number of offshore wind farms in the Baltic Sea	13	42	67
Electricity production capacities (in MW) of Baltic Sea offshore wind farms	436	10 843	25 000

Space Availability

The expected increase in the number of offshore wind parks in the Baltic Sea is going to be to be accompanied by an increase in the individual park size. This is due to the fact that the size of individual windmills is expected to increase and thus also the distances required between them. Individual wind turbines in Rødsand II in Lolland, Denmark currently have a capacity of 2.3 MW, though for 2014 Siemens is already planning serial production of offshore windmills with a capacity of 6 MW. These mills have a rotor diameter exceeding 130 m. Performance studies have shown that the optimal distance between the individual mills in a park is 7 times the rotor diameter or about 1 km for the aforementioned 6 MW windmills.

It should be noted that the overall space taken up by wind parks would be substantially greater if rotors were to remain smaller. The comparable numbers of space theoretically available for combined uses for 1 and 2 MW windmills are listed below. These estimates are made for comparison purposes only and do not suggest expected areas which could be realistically occupied by wind parks and combined uses, as it is difficult to imagine that such large expanses of the Baltic Sea would be acceptably turned into windmill parks.

60–70 parks each consisting of 400 1 MW windmills would occupy an area of at least 14,800 km^2. Here 3,700 km^2 would theoretically be available for mariculture within the offshore wind parks

70 parks each consisting of 200 2 MW windmills would occupy an area of at least 9,100 km^2 (2 % of the sea area of 370,000 km^2). At least 2,300 km^2 would theoretically be available for mariculture.

PUTTING IT INTO PERSPECTIVE

It is estimated that by 2030, the Baltic Sea Region could see approximately 4,100 offshore windmills with a 6 MW capacity, located in 65–70 parks. This would correspond to an area of no less than 3,500 km^2. Some investigations suggest that at least 25 % of the space between the individual windmills in these parks may be used for other purposes and activities such as mariculture systems.

Applications

Harvesting of Natural Fouling Agents

In its simplest form, the combination of offshore wind farms with other uses could focus on the harvest of fouling agents in the submerged parts of the windmill constructions. The algae, seaweed and mussels harvested could be used as alternative protein resources for example for fish feed or as a biomass contribution to local energy systems (gasifiers).

The yield from this type of harvesting is reported to be up to 40 kg of biomass per square meter per year in the North Sea.[5] A study from the Baltic reported a yield of 10 kg/m^2, with the biomass containing a substantial removal of heavy metals, nitrogen, and phosphorus.[6, 7]

Figure 3: Possible Combinations with Offshore Wind Parks.

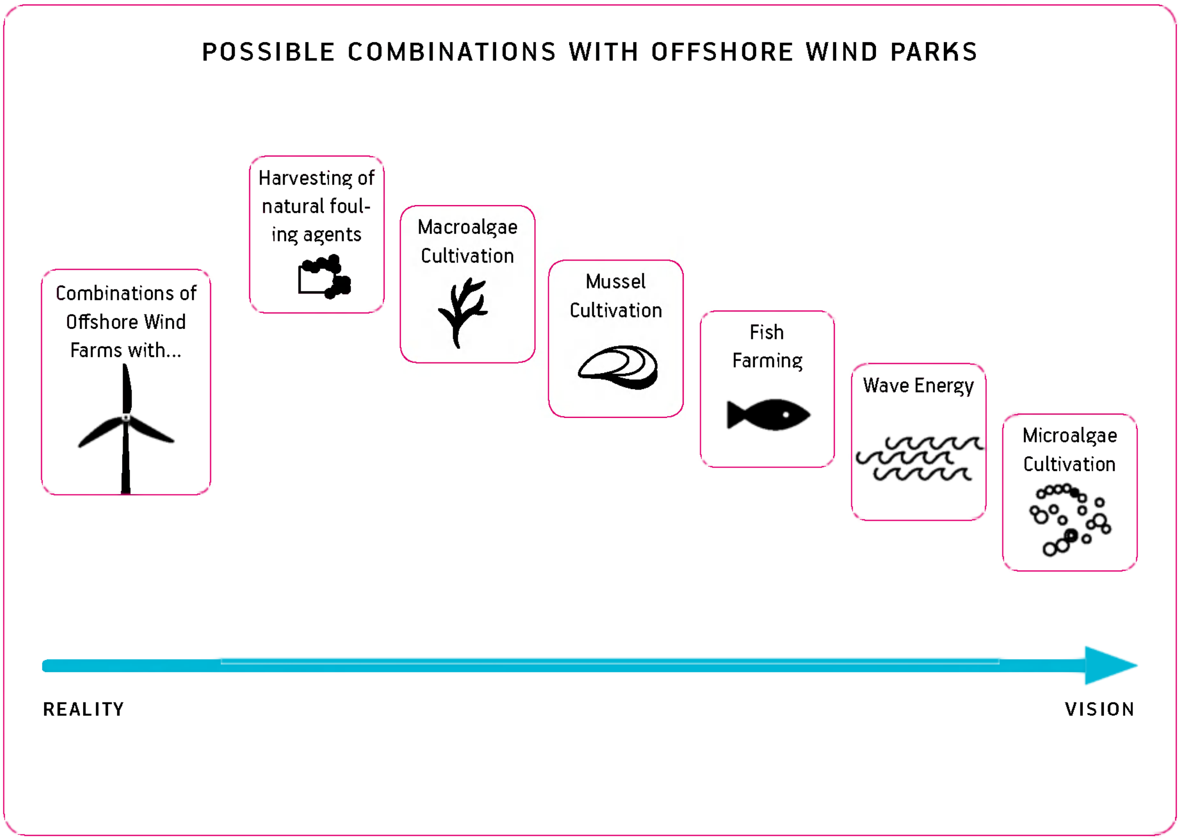


Figure 4: Fouling on wind mill foundations (photo: Mathias Andersson / Azote).

Macroalgae Cultivation

Generally macroalgae are more suitable for cultivation at sea than microalgae since they do not need to be enclosed. Usually, so-called "settling-lines" are inoculated in hatcheries onshore and thereafter placed in the cultivation systems offshore. The techniques currently used could probably also be applied in windmill parks, but there are currently no commercial examples of macroalgae cultivation within offshore wind farms. Some research and testing have taken place in the Netherlands and Denmark and more tests are planned for 2012–2013. Generally it appears that some types of seaweed may anchor well to solid structures like windmill constructions, nets and lines.

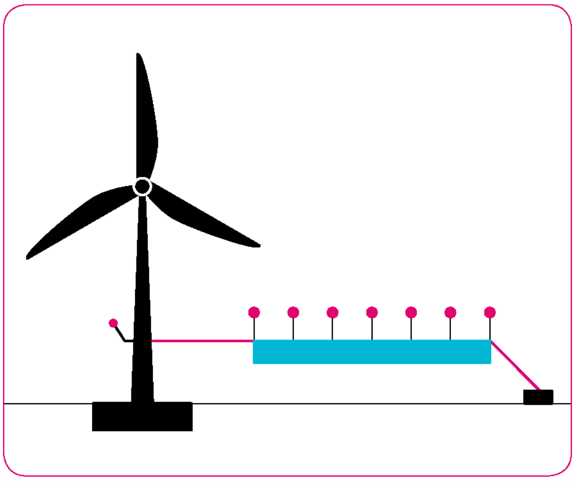
Mussel Cultivation

A Danish feasibility study has shown that mussel farming is possible in combination with windmill farms, with the mussels settling on strings, nets and solid structures and attached to the mill foundations.[8] However, the present design, operation and management of the farms as well as the rough wind and wave conditions provide challenges. Furthermore, the presence of mussels could attract birds, with increased risk of collision with turbines as a likely consequence. However, bottom culture within the parks may be a feasible alternative for increasing the mussel production areas. Large-scale production would probably reduce operating costs.

With salinity levels decreasing towards the eastern Baltic Sea, opportunities for production of high quality mussels (for human consumption) decrease in these areas. However the biomass from these areas may still be useful for other purposes, such as nutrient removal, feed and biogas production.

Calculations have been undertaken for Rødsand II, Denmark, using Swedish mussel production data[7] and assuming that nutrient removal properties of mussels would not change if the mussel farm installations were located within a windmill park. Results show a potential annual production of 2000 tonnes of mussels containing 20 tonnes nitrogen and 2 tonnes phosphorus if production facilities were to be set up on all park windmills. Thus, simple, low intensive mussel cultivation in future wind parks could account for a substantial removal of nutrients from the sea.[6] Within the SUBMARINER project, a test line for cultivating mussels and macroalgae has been installed at the Danish Rødsand II wind park in autumn 2012 (see figures 5 and 8).

Figure 5: Diagram showing system for cultivation of mussels at the offshore wind park Rødsand II. Redrawn from 6



Fish Farming

Fish farming in offshore windmill parks would consist, in its simplest form, in the installation of currently known and used fish production facilities within the area of the wind parks. These would probably be operated in cooperation with the wind park's own set up for operation and management. The proper sustainable approach would consist of the installation of Integrated Multi Trophic Aquaculture (IMTA) (see "Sustainable Fish Aquaculture" Chapter) production facilities within the wind park area.

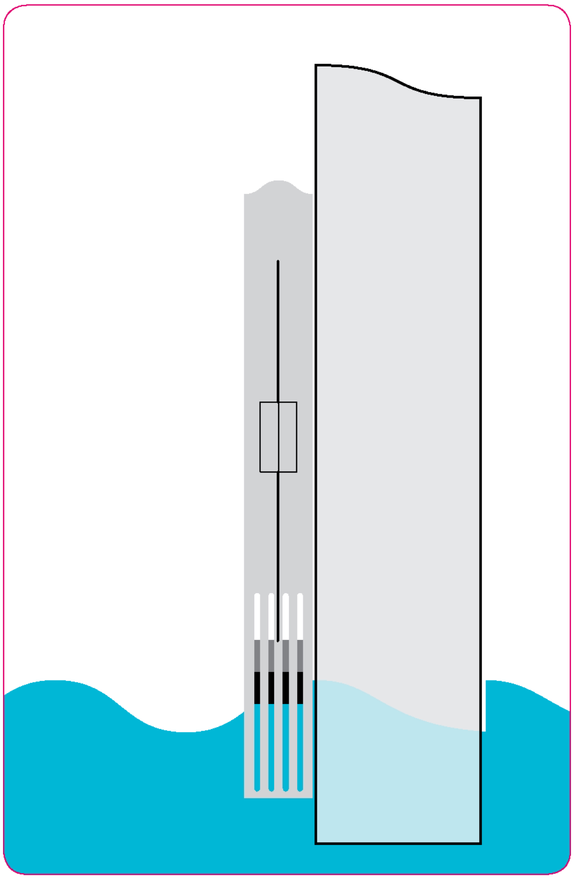
This type of combination is more feasible to take place in the future, as the individual windmill constructions increase in size and the parks will occupy larger areas, meaning that the individual towers occupy comparatively less space (less than 1 % of the park area), leaving space for other structures and production facilities between the mill towers.

Wave Energy

Recently a new combination of wind and wave energy production systems has been proposed, using the towers of the individual windmills for fixation of wave energy devices. The concept was developed at the University of Klaipeda[9] and is intended for Baltic Sea low wave conditions. It consists of closed tubes containing the wave energy generator and a buoy activating the generator. The tubes are attached to the windmill tower. The wave energy generating tubes may be anchored in a way that prevents possible vibrations, that is, symmetrically around the tower.

In the short term, due to the relative immaturity of offshore renewable energy technologies, it is generally seen as too early to deploy combined wind-wave platforms. However, co-location of devices could eventually realise large benefits with respect to infrastructure and represents an important opportunity, with benefits from joint utilisation of electrical infrastructure and potentially of operations and maintenance teams, vessels and infrastructure. Six principal areas have been identified where immediate technical synergy opportunities exist between the offshore wind and wave energy sectors:

Figure 6: Concept of a combined wind and wave energy production system.[9]



- Common foundation types
- Sharing of lessons learnt for effective array layout design
- Common mooring/fixed connection points
- Grid connection and integration
- Common power take off technologies
- Sharing of lessons learnt for effective design and technology development to reduce the need (and associated cost) for operations and maintenance (remote monitoring is a good example of this).

Both sectors can also take advantage of lessons learnt in order to accelerate their development

Figure 7: Visualisation of a windmill park with photobioreactors.[10]

and penetration into the European energy market. Both also share a similar context in terms of governmental marine policies, marine stakeholders and spatial constraints.

Microalgae Cultivation

The combination of offshore wind farms with microalgae cultivation is mostly limited by the fact that microalgae cultivation at sea is in and of itself still a challenge. Technologies currently under development, such as the OMEGA (Offshore Membrane Enclosure for Growing Algae) system, which consists of algae culture bags with osmotic membranes, could presumably also eventually be anchored to the windmill foundations.[10, 11]

Technology

Despite growing interest in the concept of combining offshore wind farms with other uses such as mariculture there are still very few concrete examples worldwide. Most references to the topic are purely theoretical and often speculative.

Substantial research on the combination of mariculture and offshore wind farms is being led by the German research center IMARE (Institut für Marine Ressourcen GmbH) in Bremerhaven.[12, 13] However, most of the research efforts have focused on North Sea wind parks and on windmill foundation types which are not common in the Baltic Sea.

In Denmark some research has been done at the Danish Technical University (DTU Aqua) mainly in an assessment study on the possibilities of farming of fish and shellfish in areas in between wind turbines, using the farm south of Nysted as a pilot case[14] and a small mussel project has been carried out at the Swedish west coast.[5]

With certainty, one important technical consideration regarding the possibility of combining uses is the choice of windmill foundations, which is in turn related to sea depth. A number of different types of foundations for offshore windmills have been developed: monopile foundations, gravity foundations, tripods and floating foundations.[15]

Tripods and floating foundations are for use in very deep water (over 100 m). In view of the rather shallow water depths (10–30 m) in which current and projected wind parks are located in the Baltic Sea, such tripod foundations are exclusively found in the German and Danish EEZ of the North Sea and in the UK EEZ.

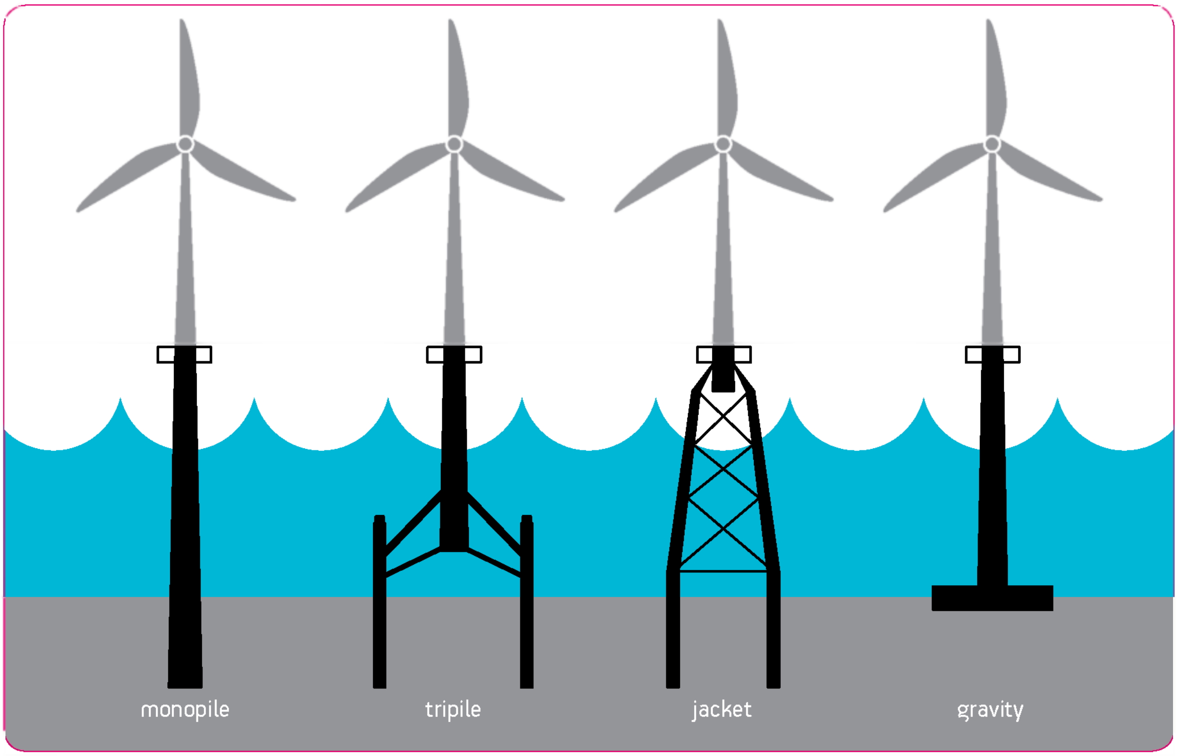
Two types of foundations are suitable at shallower depths: the monopile and the gravity foundations. A monopile is in essence a long steel rod that is hammered into the seabed. Offshore wind farms such as Horns Rev and Samsø in the Danish Baltic Sea have monopile foundations. To prevent sediment erosion large protection boulders are placed around the monopile turbine within a diameter of 20 m. A common distance between today's turbines is approximately 500 m. This implies that turbines and their boulder protection occupy less than 0.3 % of the total area of the windmill farm.

Gravity foundations can be made of either concrete or steel, concrete being the most common. The idea is to have a base structure heavy enough to support the tower and engine housing solely by its own weight. The technique is similar to that used in bridge construction and is therefore very well known. Gravity foundations are transported to the site on barges and lowered onto the seabed. The foundation often contains compartments, filled with ballast rocks to increase the total weight, which is typically a couple of thousand tons. Rødsand 2, Nysted and Middelgrunden in the Danish Baltic Sea are examples of wind farms that have gravity foundations. These kinds of foundations are expected to be the most commonly used in future Baltic Sea Region wind parks.

Other important aspects to consider from a technological perspective relate to the environmental conditions and how to best control and the impacts of storms, waves, currents and other elements. Windmill farms are generally located in areas with strong winds and often also high waves, which can hamper operations for mariculture and ship traffic. Experiences from the Horns Rev I wind farm in the North Sea show that operations are possible at wind speeds below 8 m per second, which is the case between 51–64 % of the time at the wind farms of Horns Rev, Anholt and Nysted (Denmark). Wind speeds between 8–14 m per second make operation possible only sometimes (depending on other factors), while wind speeds above 14 m per second as well as wave heights exceeding 1.2 meters hamper operations altogether. Estimates suggest

Figure 8: Test cultivation line at Rødsand II: 90 windmills, 207 MW, 75–80 km cables, area of 34 km^2 plus surrounding restricted area.

Figure 9: Offshore foundation options for windmills. Monopile and gravity foundations are suitable for shallow waters of the Baltic Sea.



that operation of offshore windmill parks in the Baltic Sea Region is possible up to 80 % of the time.

An accurate prediction of the effects of windmill structures on surface ocean circulation is of great importance to assess the suitability of wind farm installations as sites for aquaculture activities. Windmill structures will naturally have an interaction with the surface and tidal waves, which can be important in regulating local water circulation patterns. Another important factors to consider is ice cover during the winter, which can prevent or limit the operation of nearshore aquaculture sites.

Competence Centres in the Baltic Sea Region

Although the Baltic Sea Region is a leader in the world wind industry, research into the combination of uses in offshore wind farms is still at a very early stage and thus only a few actors are involved in the field. The most substantial amount of research has taken place in the United States at NASA. In Germany, IMARE hosts test facilities at a laboratory scale and undertakes research on the development of equipment suitable for the North Sea environment. In Denmark, the Green Center has been involved in research in co-localisation in the Baltic Sea Region and has very recently set up a small test site in Rødsand II (Eon) in cooperation with the local operation and maintenance unit in Rødbyhavn and the Swedish company Kingfisher.

Table 2: Research institutions, projects and companies dealing with combined uses in the Baltic Sea Region.

Research Institutes / Projects / Companies	**Focus area**
Danish Technical University DTU-Aqua (Denmark)	Offshore wind farms and their potential for shellfish aquaculture and restocking Feasibility studies on mussel cultivation in the Nysted wind park in Denmark
Algae Innovation Center (Green Center) (Denmark)	Demonstration and test facilities for algae cultivation. Test site for estimation of biomass potential in Rødsand II. Research on algae potential for different applications Contribution to local and regional development
Institut für Marine Ressourcen GmbH, IMARE (Germany)	Research on extensive open ocean aquaculture development within wind farms in the German EEZ of the North Sea Offshore co-management, legal constraints and management strategies for governing wind farm-mariculture integration, including sociological constraints
Offshore Center Denmark	Offshore cluster organisation
Kingfisher (Sweden)	Testing of equipment for offshore mussel and algae cultivation, including in offshore wind parks
Krog Consult (Denmark)	Assessment studies on the possibilities for cultivation of fish and shellfish in areas with offshore windmills. Pilot study using the wind park at Nysted.
University of Klaipeda (Lithuania)	Pilot case on co-location of wind mills and wave energy generation equipment

Environmental Assessment

Since on a practical level the concept of combining offshore wind farms with other uses is in its infancy, information on environmental impacts is limited. The following evaluation of impacts on the environment pertains to the co-localisation of windmill parks and aquaculture production facilities (e.g. algae, bivalves, fish). The possible effects of wave energy installations combined with offshore wind farms are discussed in the chapter on wave energy.

General Considerations

Marine space is nowadays considered a valuable asset in itself and increased efforts are being undertaken to keep as much of it as possible unused by promoting co-uses in spaces which are already being utilised.

From a spatial perspective, combining offshore wind farms with other uses is expected to result in a number of positive impacts such as:

- Less and better optimised use of a limited amount of space.
- Mariculture installations can be more or less hidden within offshore wind parks, minimising their impacts on the landscape.
- Benefits from the use of the existing offshore infrastructure (service harbours, boats, vehicles, electricity supply, anchorage possibilities), possibly also common operation and management facilities, resulting in reduced emissions from transport and handling.

However combinations may also lead to increased spatial problems including:

- Increased traffic intensity for operation and management, with consequent wear on waterways and increased risk of accidents with related risks to the environment.
- Disturbance of the “windmill landscape”.

Furthermore, it has been shown that windmill installations function as resting places for birds and mammals as well as create artificial reefs and related biotopes, providing new habitats and substrates for marine organisms. Any kind of added uses to the wind park may therefore lead to disturbance of the new biotopes created or the mammals and birds that have found resting places between or on the windmill foundations. However, due to the lack of real data many open questions remain about potential impacts on marine mammals and sea birds, as well as the shading of local ecosystems. The overall impact may well be positive but further research is needed.

Considerations on Specific Combinations

While many of the impacts of mussel, macroalgae and fish (IMTA) aquaculture in offshore wind farms will be similar to those expected for near shore cultivation (outside wind parks), the offshore location with its increased water depth and higher exposure to storms, high winds and wave activity creates some additional concerns regarding the sustainability of the cultures. There is also an expected increase in the carbon footprint associated with offshore cultivation in wind parks when compared to nearshore cultivation as a result of higher costs associated with harvesting and transport of biomass.

WATER QUALITY

Harvesting of natural fouling agents and the combination of mussel and/or macroalgae cultivation with wind parks is potentially an attractive means to improving water quality and mitigating against eutrophication. Conversely, the combination of fish aquaculture with offshore wind parks will most likely have unfavourable impacts on water quality by adding more nutrients to a nutrient-rich environment (even with IMTA systems, which mitigate the excess nutrients problem but do not eliminate it).

HABITAT / SPECIES PROTECTION

Given the relatively shallow water depth (c. 30 m) under consideration, many of the environmental benefits that can be realized by moving mariculture offshore (e.g. to water depths >50 m)[16] would only be moderately realized in this scenario, as coupling

Table 3: Overview of the potential different impacts of harvesting natural fouling agents, cultivating mussels and / or macroalgae and combining offshore IMTA technology (i.e. finfish, mussel and macroalgae combination) with wind parks on environmental objectives and priorities.

Environmental Objective	**Environmental Priority**	**Harvesting of natural fouling agents**	**Macroalgae Cultivation**	**Mussel Cultivation**	**Fish Aquaculture in IMTA**	**Comments**
Water quality	Bathing quality					
	Water transparency	🔵	◍	🔵	🟠 ○	
	Eutrophication	🔵	🔵	🔵	🟠 ○	
	Biogeochemical cycles	🔵	🟠 ◍ ?	🟠	🟠	Beneath the site
Habitat / Species protection	Food web dynamics	?	🟠 ◍ ?	🟠 ?	🟠	Phyto-zooplankton interactions
	Biodiversity	?	🟠 ◍ ?	🟠 ◍	🟠	Benthos and anoxia
	Benthic habitats	?	🟠	🟠 ◍	🟠	Anoxia versus shelter, food
	Bird habitats	?	🔵	🔵	🟠	Natural stocks used for feed
	Fisheries	?	🔵	🔵	🔴	Natural stocks used for feed
	Marine mammals	?	🟠	🟠	🟠	Depends on location
	Marine noise	?	🟠	🟠	🟠	Harvesting, transport effort
Coastal protection	Coastal morphology					
	Scenery					
Climate protection	CO_2 emission reduction	🟠	🟠 ◍	🟠	🟠	Harvesting, transport costs versus biogas production

🔵	strongly supportive	○	neutral
◍	moderately supportive	?	gaps in information;
🔴	strongly not supportive	blank	not applicable
🟠	moderately not supportive		

between benthic and water column processes will remain an issue. For mussel and macroalgae cultivations, the environmental impacts are similar to those detailed in the near-shore assessments covered in the respective chapters with some moderation of the unfavourable impacts assumed due to some increase in water depth and location offshore. Of greater concern, is the deployment of fish aquaculture (IMTAs) in offshore wind parks. Increased organic pollution and sedimentation will be an issue (albeit also somewhat moderated as compared to nearshore installations) and the increased exposure to the elements at offshore locations increases the risk of escape of cultured fish into the natural environment and interactions with wild fish and predators. Furthermore, various chemicals and medicines are used in mariculture which accumulate in the benthic organisms and sediments below the net cages.[17, 18] Little is know on the sensitivity of benthic habitats to these environmental hazards and medicines and there is a need for local knowledge of the prevailing currents in order to assess the full impact on the benthos.

CLIMATE PROTECTION

There will be an increase in the carbon footprint as farming moves offshore due to increased harvesting and transport costs. On the other hand, a potential co-use of existing infrastructure, operation and management facilities could actually result in reduced emissions from transport and handling.

Overall, the culture of mussels and macroalgae in combination with offshore wind parks can be encouraged as a water quality remediation effort. On the other hand, not enough is known about the real impact on water quality of deploying new open fish cages as part of an IMTA system within an offshore wind park and this can therefore not be recommended for the time being.

Socioeconomic Aspects

Offshore wind energy is a market with great potential. Much of the technology is currently concentrated around Northern Europe and Denmark in particular. To date, 90 % of all installed offshore capacity in the world has been delivered by the Danish wind power industry and a substantial expansion of the market is expected in coming years.

Investment costs are by far the most important factor. Operation and management costs are estimated to be approximately € 0.012–0.015 per kWh of produced wind power, corresponding to 2–3 % of total turnkey investment costs in the early years of the farm and around 5 % at the end of the lifetime.

Currently offshore wind energy remains more expensive to produce than conventional energy. This is publicly and politically accepted given renewable

IMPORTANT ASPECT FOR THE BALTIC SEA REGION

Maritime Clusters: A Path to Promoting Combined Wind Farm Development?

In the port cities of Bremerhaven (Germany) and Esbjerg (Denmark) comprehensive offshore wind farm supply chains have been built up with numerous companies producing the different elements for the offshore wind farms (e.g. towers, blades, engines). Location close to the harbour makes construction of wind farms a faster and more efficient process. While these clusters are currently located in the North Sea, such solutions could prove not only viable in the Baltic Sea but also an important tool in offering model solutions for combined uses in future wind parks.

energy targets. The additional costs of producing electricity with wind turbines, including offshore ones, are paid by the electricity consumers.

Even though some wind power companies are interested in potentially combining other uses in the same space, operation and maintenance of the turbines and installations have highest priority. This involves small boats, larger barges, cranes and other equipment and is a challenge to the design possibilities and management of potential mariculture systems within the same spaces.

While it is possible that positive synergistic effects resulting from the additional uses of areas underneath or between the mills may outweigh the additional cost associated with them, this is unlikely to be the case. Thus, if combined uses can be successfully implemented in offshore wind farms, options to reward the costs attributable to any derived bioremediation or other environmental and societal benefits (such as nutrient removal, increasing fish stocks, jobs in rural areas) are needed. This would also improve public approval. In order to create attractive incentives for combined uses resulting in bioremediation, compensation for providing ecosystem services (e.g. nutrient trading schemes) will need to be introduced as otherwise the costs of combining uses would probably be prohibitive.

Regulatory Framework

Even though spatial efficiency is a concept promoted by maritime spatial planning, in current planning reality "combined" uses are much more difficult to be approve than singular uses. In Germany and Denmark there is, for instance, a comprehensive regulatory framework in place for offshore wind energy, but a less developed regulatory framework for the different forms of aquaculture. It should be noted that so far there is no case where licensing agencies had to decide on an application for aquaculture within an offshore wind park. It is therefore necessary to have a satisfactory regulatory framework which is able to deal with the special situation of aquaculture within an existing or planned offshore wind farm, especially taking the technical interface between these two uses into account. Otherwise the establishment of mariculture operations in very suitable locations in the Baltic Sea could be hindered if these places are taken by wind farms without the possibility to have at the same time or later a co-use with aquaculture.

ADDITIONAL POINT

THE DANISH LEGAL FRAMEWORK

In Denmark, the Danish Energy Agency is the authority responsible for planning and implementation of offshore wind turbines.[19, 20, 21] It acts as a "one-stop shop to provide all necessary approvals and licences. Relative to the administrative processes in other countries, the Danish model has created a quick and cost-effective process benefiting both individual projects and the development of offshore wind industry as a whole. The consent procedure includes steps of political decision-making at the national level, tendering, concession to the successful tender, license to pre-investigate the sites, environmental impact assessment, construction consent (with conditions) and license to produce electricity.In order to ensure that the future development of offshore wind turbines does not clash with other major public interests and that it is carried out with the most appropriate socioeconomic prioritisation, the Danish Energy Agency, in conjunction with the other relevant authorities, has mapped the most suitable sites for future offshore wind farms and also carried out a strategic environmental assessment[19] in order to prevent any future conflicts with environmental and natural interests. However, co-localisation or combination of uses have not been considered in this process.

Even though a similar process is needed for approval of an aquaculture production facility offshore, the legal authorities involved differ depending on the type of organisms cultivated and locality of the planned aquaculture site (distance from shore). For mussels and other bivalves, the Danish Directorate of Fisheries is the legal authority. The focus is on sailing routes, buoys and anchoring and disturbance of fishing grounds. Feed and chemicals are not approved. However, in recent years no new approvals for marine fish productions have been issued due to environmental uncertainties and potential consequences on the implementation of the EU Water Framework Directive.

The legal framework for approving the cultivation of macroalgae is somewhat similar, though installations close to the coast may be approved by the local municipality.

SWOT Analysis

STRENGTHS	WEAKNESSES
• Optimises use of restricted space in the Baltic Sea • Can deliver multiple products (e.g. biogas, fertilizer, seafood) and services (e.g. energy, wastewater treatment, carbon sequestration) from the same space • Can help meet the increasing need to shift from fisheries to marine aquaculture while not losing jobs • May provide economies of scale and cooperation • Contributes to various Baltic Sea Region goals to: sustainably use marine resources, reduce environmental impacts, use space better and develop the mariculture sector • Can promote the development of economically less developed (rural) areas along the Baltic coasts	• Technology is still on an experimental stage and research is mostly focused on waters deeper than the Baltic Sea • Lack of concrete examples worldwide • Engineering challenges remain pertaining to e.g. enclosure systems, materials, corrosion, strength and longevity • Knowledge gaps remain concerning sectorial cooperation and environmental impacts • Mariculture tradition in the Baltic Sea Region is limited • Limited areas with suitable conditions for wind parks • No tradition for cooperation between the aquaculture and offshore wind sectors • Resistance from both the wind and mariculture industries

OPPORTUNITIES

- Spatial efficiency has been introduced as a principle of maritime spatial planning in the Baltic Sea Region and is thus promoted by planning procedures
- Growing development in innovation and technological progress
- University and training courses already exist which can provide qualified employees in some of the necessary areas
- EU support EU 2020 policies concerning e.g. renewable energy, climate change, Integrated Maritime Policy, structural funds
- Growing demand for energy from alternative sources
- Growing prices for traditional energy carriers

THREATS

- Difficult and long approval procedures
- Potentially increasing nature protection requirements
- Resistance to new licences for marine aquaculture in general
- Potential for conflict between opposing stakeholder interests
- Lack of political support at national level in the form e.g. of national energy policies ensuring stable level of energy prices from renewable sources
- Lack of investment and financial support due to the actual economic and financial crisis
- Lack of political demand, public awareness and support

Knowledge Gaps

The combined use of wind farms with other applications in the Baltic region is still an innovative vision. There are still a myriad issues to be elucidated before the vision can be realised since there is an almost complete lack of practical experiences on the establishment, operation and maintenance of combined uses.

There is a need for further knowledge and experiences on:

- Economies in common operation and management
- Economic feasibility of co-localisation in general
- Technical solutions for cultivation systems, as we know very little about the technical feasibility of the aquaculture different systems (strings, nets, anchoring, mountings) in connection with the windmill foundations (particularly with gravity foundations) or in “empty” spaces between the windmills.
- Information regarding whether the windmill constructions would need to be changed to resist additional drag from the equipment posed on them.
- Information about what are the most suitable sites for aquaculture within the wind parks (e.g. bottom cultures)
- Comparative data on the cost of removing nitrogen from the ocean vs. still on land?
- Environmental impacts:
  - Effects on surface circulation, local circulation, possible reduction of wind stress in farms
  - Remediation potential
  - Shading of the local ecosystem
  - Effects on marine mammals and birds
  - For harvesting natural fouling agents, monitoring the local ecology regularly and assessing the efficiency of communities to re-establish themselves after harvesting and the impact of harvesting on food web dynamics and biodiversity.
- Information on the extent to which the same energy grids can be used for combined wind and wave energy in the parks

- Could the energy produced by the windmills on site be used for the operation of other parallel productions on the site? Is there an easy access to sustainable energy for running the combined production facilities?

Conclusions

The aim of developing combined uses in wind farms in the Baltic Sea Region is the contribution to the production of sustainable healthy food, jobs, scientific and technical experience, and environmental benefits such nutrient uptake while making the best possible use of space, a restricted resource in the region. The concept of combining uses is tied to the core principles of a “Blue Economy”: using what you have, looking for multiple benefits and keeping it simple. The ideas that stand behind the concept thus fit perfectly within the recently adopted strategy for a sustainable bioeconomy in the EU.

The potential area for implementation of the combined uses in the Baltic by 2030 is roughly calculated to be at least 850 km^2 and probably much more. Implementation of the concept has the potential to aid in the development of less economically developed (rural) areas along the Baltic coast and to create a base for the development of new industrial and knowledge clusters. This knowledge can then be exported to other areas with similar conditions such as the Big Lakes in the United States, the Gulf of Mexico, or South East Asia.

However, there is a lack of tradition among wind power companies and the aquaculture sector to cooperate for the use of space and for operation and management. Whereas aquaculture is struggling to find suitable locations for new activities, the wind companies are the first to move into the areas. For wind farm developers the focus is – other things being equal – to produce the highest rate of electricity at the lowest cost. Even though management of offshore wind energy sites at the local level may in many instances agree with the perspectives of combined uses, the corporate management level usually blocks such initiatives.

The implementation of combined uses in the Baltic Sea Region would first require convincing evidence from demonstration plants and pilot tests with respect to environmental results, economy of cooperation and scale and technical evidence (suitable production systems). While it remains an open question whether positive synergistic effects of parallel uses would outweigh the additional costs associated, it is clear that political support by means of incentives for new solutions could do much to help promote the concept.

Recommendations

While it is abundantly clear that further research on the overall impact of combined uses is necessary to cover many knowledge gaps relating to this very innovative concept, the following recommendations can also be suggested:

- Work with offshore wind energy companies on the topic of corporate social responsibility with regards to combined uses should be initiated.
- The possibilities and conditions for establishing collaborative relationships with local wind organizations should be explored.
- Experimental sites in the new parks planned should be set up to target knowledge gaps on the feasibility of proposed combined uses (social, technological, economic, environmental, remediation potential, biomass potential).
- There is a need for political and legislative attention. The discussion on establishing legal and planning incentives to promote co-locating other productions within offshore wind farms should be undertaken at the Baltic Sea Region and EU levels.
- In order to create attractive incentives for combining wind farms with uses, which provide water quality remediation benefits, compensation for providing ecosystem services, e.g. nutrient trading schemes, should be considered as a means of bringing down prohibitively expensive costs.

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Overall Conclusions

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THIS SUBMARINER COMPENDIUM HAS NOT ONLY SHOWN THE ENORMOUS RANGE OF POSSIBLE NEW USES OF BALTIC MARINE RESOURCES AND THEIR STAGES OF DEVELOPMENT, but also the multitude of perspectives from which they need to be assessed, corresponding question marks and development needs. It has been demonstrated that a complex interplay between various disciplines is necessary in order for them to reach their full development potential and thus to form an important part of a European innovative and low-emission, climate-neutral bioeconomy which reconciles demands for sustainable agriculture and fisheries, food security, sustainable use of renewable biological resources for industrial purposes, all the while ensuring biodiversity and environmental protection.[1]

The concluding points in each chapter show that the chances as well as requirements for each new marine use differ substantially. Nevertheless, a number of cross-cutting issues have been identified that apply to several if not all innovative uses analysed. They are evidence of the necessity to further pursue and promote interaction between the various research disciplines and initiatives analysed in the frame of SUBMARINER and form the basis for the following SUBMARINER findings and Baltic Sea Region wide recommendations.

A Holistic Approach to New Marine Uses

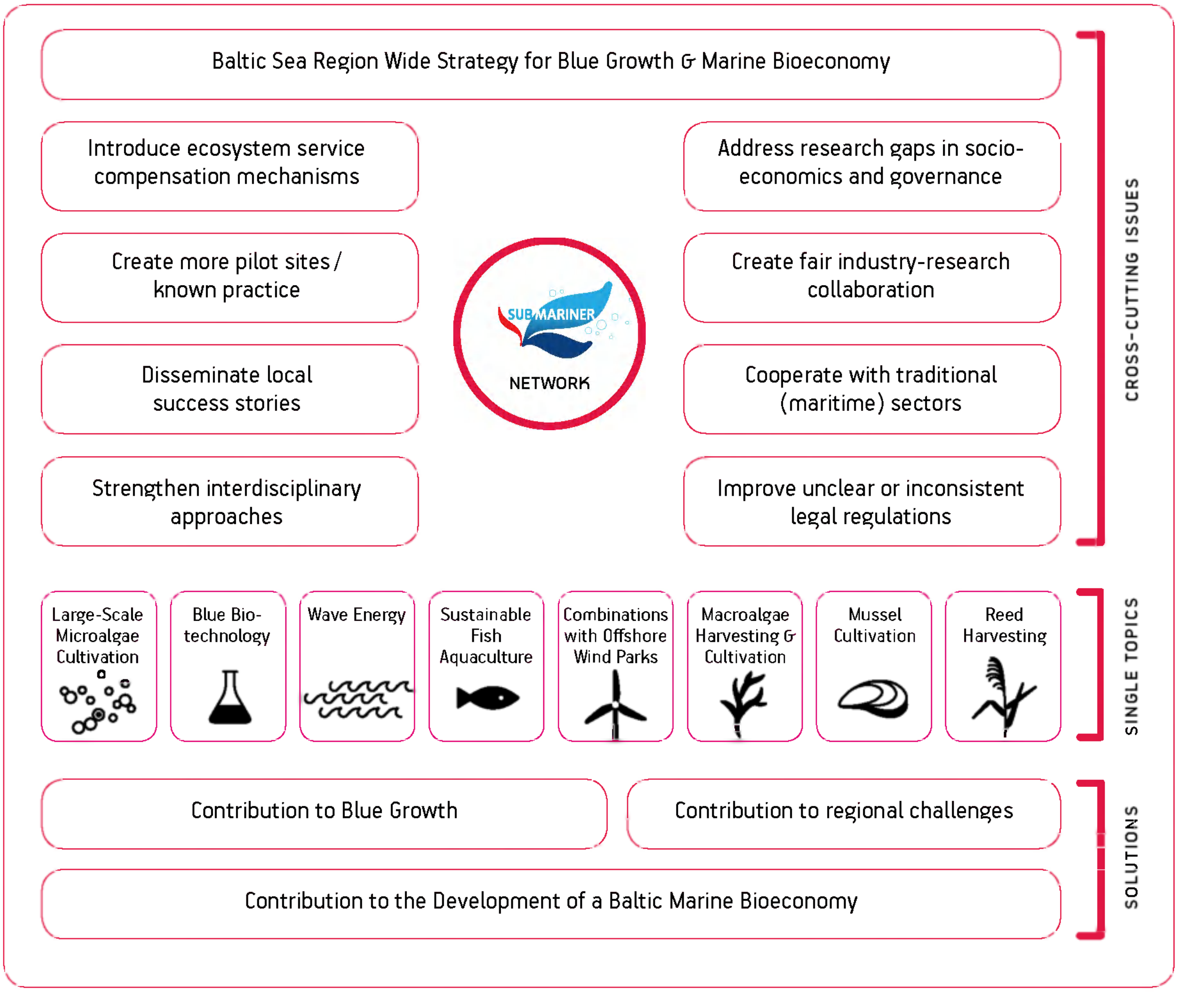
The Baltic Sea Region as a Potent Partner in Global Blue Growth

Large-Scale microalgae cultivation for biofuel, **Blue Biotechnology**, **wave energy** and **sustainable fish aquaculture** are among the new marine uses for which enormous growth and market potential is anticipated not only at European, but even global scale. These new marine uses have also been highlighted as Blue Growth Focus Areas in the most recent EU Communication on opportunities for marine and maritime sustainable growth.[2]

This Compendium has shown that although Baltic Sea conditions may be less favourable than those in other European or global seas, the region could still become an important player in the sectors related to these uses within a relatively short time.

Positive factors are not only the existing R&D capacities in aquatic science as well as marine / energy technologies but also the high level of transnational cooperation across the region (as encapsulated within the EU Strategy for the Baltic Sea Region), which merely needs to be given more focus towards these areas. While these sectors may be significantly fostered by specific sub-regional approaches (i.e. cluster building), their development would greatly benefit from a higher level, Baltic Sea Region wide, cooperation. It has also been shown that Baltic Sea resources may be directly suitable for such applications to take place. Furthermore, the region could reap substantial socio-economic benefits from becoming the knowledge and technology development hub in a given field, even if the application itself is realised elsewhere and/or with resources from other seas.

Figure 1: Summary of Overall Conclusions from the SUBMARINER Compendium.



An important contribution to regional challenges

Although **reed** and **macroalgae harvesting** as well as **mussel farming** for other purposes than seafood may not have such a global and/or European appeal, they may be of importance to the Baltic Sea Region in the future. They can especially be attractive to some of the coastal regions in search of cost-efficient environmental remediation schemes and/or renewable energy sources. In view of their contribution to water quality remediation, they also help promote coastal tourism, another one of the Blue Growth Focus areas identified on a European scale.[2] More importantly, their appeal derives from the fact that these applications are at a stage of development in which pilot projects can be turned into real applications with only limited investment needed and clear, immediate benefits can be realised for the local communities.

Although the actual implementation of these opportunities may be driven by sub-regional players, the extent to which their potential can be exploited remains to a certain degree dependent on political will and action to reduce existing regulatory barriers across the whole Baltic Sea Region. In most cases, private investments will only become attractive if real payments are introduced for the ecosystem services delivered by those uses. Furthermore, all three marine uses are affected by EU Directives (such as the EU Habitats and Birds Directives), which of these uses. might in some cases require reinterpretation in view

Innovation: More than just technological advance

This Compendium has shown that the uses analysed differ in their actual stage of development, ranging from initial concepts and preliminary research up to pilot stages or even some local scale start-up applications. Nevertheless, even for the most long-standing uses such as reed harvesting, some **serious knowledge gaps** and question marks still remain.

The reason for this stems mainly from the fact that their advances not only depend on technological development but also on the introduction of innovative, system based solutions within the underlying legal and economic framework. Applications and research have so far mainly been driven by the natural science community. While a number of serious advances are still required in this area, the critical gaps in research have actually been identified in the field of socio-economics and governance.

Blue Biotechnology, both for high value ingredients or for large-scale cultivations, not only depends on excellence in the natural science field but also on finding **viable solutions for collaboration between private industry and publicly financed research**. Similarly, the potential for using marine resources for bioenergy is not merely a technical question; it also depends on the development of decentralised energy networks, smart logistics and business solutions. In cases such as mussel farming and macroalgae or reed harvesting technological barriers are expected to be overcome in the near future, with innovation mainly required in the way in which ecosystem services can be recognised as real quantifiable values.

Working with, not against traditional (maritime) sectors

All of the applications considered by SUBMARINER are to be understood in connection to the traditional maritime sectors such as fisheries, shipping or coastal tourism as well as the new players such as offshore wind energy production. Land-based knowledge also needs to be taken into account, e.g. covering the whole range of competence centres in bioenergy or biotechnology. In many areas, innovation does not mean development of a completely new sector but merely the expansion of perspectives from land to sea resources.

This has already been shown for environmental remediation but the same is true concerning the use of existing biotechnology laboratories for “blue” research, expanding resource considerations for existing bioenergy strategies or thinking of smart combinations between fish aquaculture and agriculture systems (greenhouse). Furthermore, many technologies can evolve from those used by more traditional sectors, as evidenced by the strong linkages between wind and wave energy technology companies.

Building on SUBMARINER local success stories

This SUBMARINER Compendium provides plenty of evidence that despite the multitude of European level strategies the real drive for innovative applications comes from **bottom up initiatives** of successful local or sub-regional collaboration between a few individual scientists and forward thinking decision-makers in political or private sector spheres. Municipalities like Trelleborg (SE) or Solrød (DK), regions like Schleswig-Holstein (DE) or Åland (FI) and Kalmarsund areas (SE), small companies like CRM (DE) or AstaReal (SE) all have in common that they have readily perceived the value of some of the proposed SUBMARINER applications and turned them into viable

Figure 2: A pilot mussel farm at Kumlinge, Åland islands.

business and/or public service models at local or regional scales.

These cases show that action is possible even at this stage of development and they are important forerunners for the possible mainstreaming of some of the SUBMARINER ideas. Thus, there is a need for joint Baltic Sea Region efforts to **create more such pilot sites and "known practices"**, promote and disseminate success stories and collaborate within and beyond the Baltic Sea Region scope.

The need for a Baltic wide cooperation strategy

A Baltic Sea Region wide strategic approach or network could not be identified for any of the innovative uses analysed. Initiatives take place either at local scales or on a project oriented basis with little regard for Baltic-wide and/or cross-sectoral cooperation. If the Baltic Sea Region wants to become a model in blue growth and sustainable exploitation of the sea, different forms of **Baltic-wide cooperation and networking** have to be established between a core group of interested decision and policy makers from sub-regional up to transnational levels, researchers, financial intermediaries, development agencies, companies and the resource sectors.

The field of Blue Biotechnology (including large scale microalgae cultivation) has been identified as the area which would most benefit from the adoption of a Baltic Sea focused strategy through which researchers, laboratories and industry stakeholders could be brought together in a target oriented network to create the necessary links between the various elements of the long value chain. Given the wide range of potential applications within this field it is necessary to pick out the most relevant for the Baltic Sea Region. But all other innovative uses considered here, including those with more regional dimensions, would also benefit from such structural cooperation. As has been shown in the field of reed or macro-algae harvesting for instance, no common inventory or monitoring is taking place, which makes it difficult to assess the true potential for those applications.

System Understanding and Interdisciplinary Approaches

All new uses require holistic approaches to the analysis of their effects. Separately they might seem economically unfeasible but when considering all effects together – direct as well as indirect – uses reveal interesting opportunities. There is a need for new instruments allowing measurement and synthesis of different types of benefits taking into account the extent of positive, negative as well as cumulative effects both from an environmental as well as an economic point of view.

The concept of **harnessing multiple uses** is best exemplified by the bio-refinery concept shown in the "Large-Scale Microalgae Cultivation" chapter. In the case of reed, mussel or macroalgae, the capacity for nutrient removal alone may not justify their harvesting and/or cultivation. However, further processing of these resources into biogas, feed, fertilizers or insulation material leads to additional environmentally friendly products with an economic value as well as added benefits such as clean beaches or more sustainable fish feed, all of which should be taken into account. Integrated multi-trophic aquaculture (IMTA) takes the idea even further by not only looking for multiple products from one application but also combining various applications. Even Blue Biotechnology should not be understood merely as an independent discipline with immediate applications (i.e. in human health) but as a supporting discipline that provides the basis for making other blue growth applications feasible, e.g. by providing sustainable feed supplies for fish aquaculture, improving the efficiency of the macroalgae digestion process for biogas production or offering new solutions for environmental monitoring, as well as contributing to other areas of bioeconomy (i.e. more resource efficient industrial processes).

Furthermore, all uses need to strengthen their **interdisciplinary approach**. For example, for microalgae there is a need for techno-economic models, while reed, combined uses and macroalgae require better ecological insight. This, in addition to the need for networking, should be reflected in the support conditions of external financial sources such as EU Framework Programmes or national operational programmes supporting the knowledge based bio-economy.

Ecosystem service compensation

The introduction of a mechanism to **compensate for providing ecosystem services**, e.g. nutrient payment schemes, is a key issue identified for reed, mussels and micro- as well as macroalgae applications. Sustainable aquaculture also depends partly on public funding, e.g. for restocking measures. If the Baltic Sea Region countries are serious about reaching their nutrient reduction targets as well as good environmental status in general, **financial incentives** have to be provided for those who contribute to achieving them. Nutrients payment schemes may change the entire philosophy of fighting against eutrophication and make room for new solutions in this field.

The applications demonstrated in this SUBMARINER compendium are by no means to be understood as the sole and only solutions, but they should at least be given due regard within the mix of possible environmental remediation measures. It is not the intention to replace upstream, point-source remediation measures but to bolster these with additional downstream measures. Payment schemes could be designed so as to be applicable to both aqua- and agriculture based possibilities. The extent to which an application provides an ecosystem service will be largely site dependent, thus it is anticipated that the market will regulate itself such that an optimal mix of measures will be found in each case.

Creating necessary framework conditions for win-win solutions

Inconsistent or rather **unclear legal regulations** and complicated spatial planning procedures are additional barriers. It seems that they are mainly tied to the fact that most uses are at such early and innovative stages of development that they were not sufficiently considered when these provisions were designed. This has been particularly highlighted in the case of macroalgae, microalgae, reed and combined uses. The scope of required improvements is broad, from simple legislation regulating the operation of a given use to necessary reinterpretation of EU Directives and advanced concepts like international nutrient trading schemes.

At the same time a holistic approach to marine resource uses also requires the **provision of incentives supporting collaboration** and promoting win-win solutions. This is due to the high transaction costs of cooperation between sectors (such as energy and mariculture) having no tradition of doing so, no cooperation channels and no common language despite the fact that such combinations are politically desirable (e.g. spatial efficiency, IMTA, etc.). Such incentives could cover non-sectoral or cross-sectoral funding, non-sectoral planning and programming, political demand and more attention to corporate social responsibility. The already existing cooperation between VASAB and HELCOM in promoting Maritime Spatial Planning based on cross-sectoral dialogues may provide an opportunity in developing such models.

The establishment of more favourable conditions including venture capital funds for public-private partnerships needs to be considered. There is a need for a farsighted vision on this in all Baltic countries. The Blue Growth and Bioeconomy Initiatives of the EU Commission can be useful vehicles but should be translated into national procedures, instruments and targets.

Figure 3: SUBMARINER Blue Biotechnology Cooperation Event in Kiel, Germany in May 2012

"Sea: Our future"

Overall this Compendium reveals a **low level of awareness** not only among the general public but also among national stakeholders and beneficiaries. This applies not only to the innovative potential of the sea, but also to the role of the sea in general for the economy as well as the environment. Naturally, coastal regions are closer to new developments, but even here the majority of political strategies do not take the sea into due account.

There is a need to increase the visibility of the role of the sea for the economy and environment, and its innovative potential across the whole region while also allowing for continued and strengthened interdisciplinary, cross-sectoral approaches and various combinations between research initiatives and practical applications. All of these ingredients are necessary to realize the win-win solutions described in this chapter and through the whole compendium. The establishment of the SUBMARINER Network is the first step in this direction.

References

1 „Innovating for Sustainable Growth: A Bioeconomy for Europe", COM, 13.02.2012

2 Blue Growth. Opportunities for marine and maritime sustainable growth. COM (2012) 494.

Abbreviations:

AFS:	International Convention on the Control of Harmful Anti-Fouling Systems on Ships
BDF:	Baltic Development Forum
BSAP:	Baltic Sea Action Plan
BSR:	Baltic Sea Region
CBD:	United Nations Convention on Biological Diversity
CBSS:	Council of the Baltic Sea States
CCS:	Carbon Capture and Storage
CPMR:	Conference of Peripheral Maritime Regions
EC:	European Commission
EEA:	European Environment Agency
EEZ:	Exclusive Economic Zone
EFF:	European Fisheries Fund
EIA:	Environmental Impact Assessment
EMFF:	European Maritime and Fisheries Fund
EPA:	Environmental Protection Agency
EPC:	European Patent Convention
EPO:	European Patent Office
ERA:	European Research Area
ESF:	European Science Foundation
EUSBSR:	EU Strategy for the Baltic Sea Region
FAO:	Food and Agriculture Organization of the United Nations
GDP:	Gross domestic product
GVA:	Gross Value Added
HELCOM:	The Baltic Marine Environment Protection Commission (also known as Helsinki Commission)
ICZM:	Integrated Coastal Zone Management
IEA:	International Energy Agency
IFFO:	International Fishmeal and Oil Organisation
IMTA:	Integrated Multi-Trophic Aquaculture
KBBE-NET:	Knowledge Based Bio-Economy Network
MSP:	Maritime Spatial Planning
NAFTA:	North American Free Trade Agreement (NAFTA)
NER:	Net Energy Ratio
OECD:	Organisation for Economic Co-operation and Development
R&D:	Research and Development
RAS:	Recirculating Aquaculture System
UNCLOS:	United Nations Convention on the Law of the Sea
UNFCCC:	United Nations Framework Convention on Climate Change
VASAB:	Visions and Strategies around the Baltic Sea
WWF:	World Wide Fund for Nature

Units & Measurements:

Energy

MJ: megajoules; 1 MJ = one million (10^{6}) joules (J)
GJ: gigajoules; 1 GJ = one billion (10^{9}) joules (J)
MW: megawatt; 1 MW = one million (10^{6}) watts (W)
GW: gigawatt; 1 GW = one billion (10^{9}) watts (W)
TW: terawatt; 1 TW = one trillion (10^{12}) watts (W)
PW: petawatt; 1 PW = one quadrillion (10^{15}) watts (W)
Wh: watt hour, 1 Wh = one kilowatt (1 kW) of power expended for one hour (1 h) of time
MWh: megawatt hour; 1 MWh = one million (10^{6}) watt hours (Wh)
TWh: terrawatt hour; 1 TWh = one trillion (10^{12}) watt hours (Wh)
kW/m: wave power unit (transport of energy in kW per m ocean surface)
MWh/m^{2}: wave energy density unit (instantaneous wave energy in MWh per unit area in m^{2})

Mass

mg: milligram; 1 mg = one-thousandth (10^{-3}) of a gram (g)
µg: microgram = 1 mg = one-millionth (10^{-6}) of a gram (g)
t: metric tonne = 1,000 kilograms (kg) = 1 megagram (Mg)
Mtn: megatonne = one million (10^{6}) tonnes (t)
dwt: dry weight tonne

Others

PSU: practical salinity units
µm: micrometre; 1 µm = one-millionth (10^{-6}) of a meter (m) = one-thousandth (10^{-3}) of a millimetre (mm)
ha: hectare = 10,000 m^{2}

The SUBMARINER Project

The Baltic Sea Region faces enormous challenges including new installations, fishery declines, excessive nutrient input, the effects of climate change as well as demographic change. But novel technologies and growing knowledge also provide opportunities for new uses of marine ecosystems, which can be both commercially appealing and environmentally friendly. Through increased understanding and promotion of innovative and sustainable new uses of the Baltic Sea, SUBMARINER provides the necessary basis for the region to take a proactive approach towards improving the future condition of its marine resources and the economies that depend on them.

Compendium: Describing current and potential future marine uses

- Comprehensive inventory of current and new uses
- Strengths, weaknesses, opportunities and threats to the BSR
- Environmental and socioeconomic impacts
- State and availability of technologies
- Market potential
- Gaps and obstacles in the legal framework

Regional Strategies: Testing new uses in real conditions

- Feasibility studies for new uses
- Technological and financial needs
- Impacts on environmental and socioeconomic conditions within the area
- Specific legal constraints

BSR Roadmap: Recommending necessary steps across all disciplines to promote beneficial uses and mitigate against negative impacts

- Research topics
- Institutional and network initiatives
- Legal changes (e.g. spatial plans)
- Environmental regulations
- Economic incentives

BSR Network: Bringing relevant players together

- Business cooperation events for algae and mussel cultivation, blue biotechnology industries, wave energy, and reed utilization
- Network structure (incl. membership, mission, independent finances, business plan, etc.)
- Virtual information and exchange platform
- Regional, national and BSR-wide roundtables and seminars on new marine uses

SUBMARINER Partners

POLAND:

- Lead Partner: The Maritime Institute in Gdańsk
- Gdańsk Science and Technology Park

GERMANY:

- Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
- Norgenta North German Life Science Agency
- Kieler Wirkstoff-Zentrum am GEOMAR | Helmholtz Centre for Ocean Research Kiel
- University of Rostock
- BioCon Valley Mecklenburg-Vorpommern e.V.

DENMARK:

- ScanBalt
- Lolland Energy Holding

SWEDEN:

- Royal Institute of Technology (KTH)
- The Royal Swedish Academy of Sciences
- Trelleborg Municipality

ESTONIA:

- Tallinn University of Technology
- Entrepreneurship Development Centre for Biotechnology & Medicine

LITHUANIA:

- Klaipeda University Coastal Research and Planning Institute
- Klaipeda Science and Technology Park

LATVIA:

- Ministry of Environmental Protection and Regional Development of the Republic of Latvia
- Environmental Development Association

FINLAND:

- Finnish Environment Institute – SYKE

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The SUBMARINER Compendium provides, for the first time, a comprehensive assessment of the potential for innovative and sustainable uses of Baltic marine resources. The current state of knowledge has been gathered and set against the backdrop of environmental, institutional and regulatory conditions for the following topics:

- Macroalgae Harvesting & Cultivation
- Mussel Cultivation
- Reed Harvesting
- Large-Scale Microalgae Cultivation
- Blue Biotechnology
- Wave Energy
- Sustainable Fish Aquaculture
- Combinations with Offshore Wind Parks

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