SUBMARINER

Sustainable Uses of Baltic Marine Resources

SUBMARINER Report 4/2013:

New Uses of Marine Resources in the Baltic Sea Region: General Environmental Assessment

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Abstract

Conscious application of new uses of marine resources in the Baltic Sea Region demands careful consideration of the impact the new use will have on an environment that is already under significant stress. This report describes the background, approach and results of the environmental assessments carried out in the framework of the SUBMARINER project. The objective of the environmental assessments is to systematically evaluate the impacts a single and/or combined new use of a marine resource may have on the natural environment. An Ecosystem-Based Management approach is adopted which draws on relevant issues from existing good practice, guidelines, policy and legal instruments. The aim is to highlight appropriate environmental solutions which address environmental priorities at their source. The intention is not to carry out a full environmental impact assessment but to evaluate the scope of environmental issues that are pertinent to the Baltic Sea Region and SUBMARINER new uses, and highlight gaps in information where further research is needed.

URL

The report is available for download at the SUBMARINER project's website at http://publications.submariner-project.eu

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Content

1. Rationale

The purpose of this report is to document the background, approach and results of the environmental assessments carried out in the framework of the SUBMARINER project. The report is intended to provide supplemental information to support the SUBMARINER Compendium: An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources (Schultz-Zehden and Matczak, 2012).

2. Introduction

The Baltic Sea is one of the world's largest semi-enclosed bodies of brackish water. It is almost entirely land-locked with very limited water exchange (Lass and Matthäus, 2008). The water residence time is typically 25 – 30 years. The region extends over two climate zones. The catchment areas in the north and northeast (Figure 1) are sparsely populated (1 - 30 inhabitants km^{-2}), with mostly boreal forest dominating the land cover (56% - 97%) and have a humid, sub-polar climate. The catchment areas in the south and southwest are densely populated and have an oceanic, temperate climate, with productive soils that support intensive agriculture.

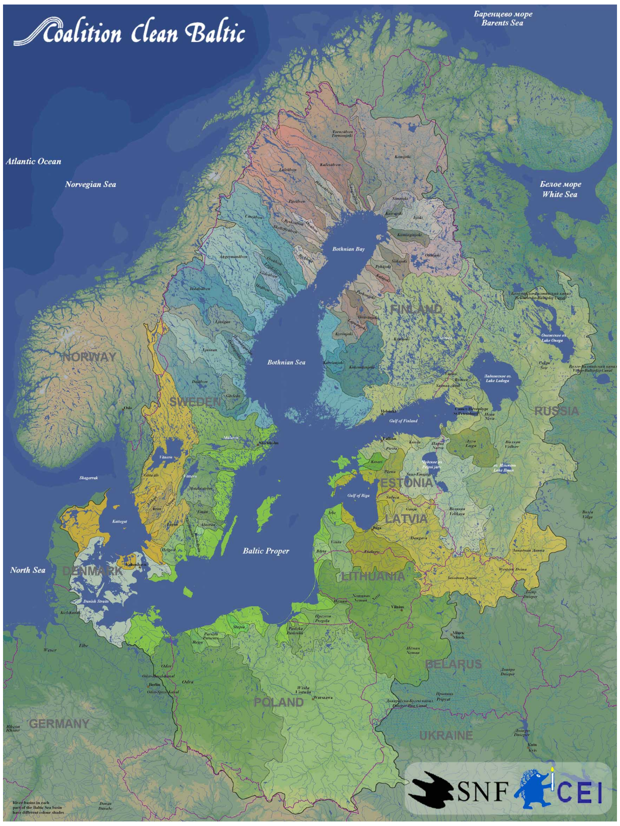


Figure 1: Baltic Sea Region Catchment Areas (source: SNF, CEI)

The total annual freshwater input to the Baltic Sea is 480 $km^3\ y^{-1}$. Almost two thirds of this drains from hundreds of small catchments into the northern Baltic Sea from the northern Gulf of Bothnia (200 $km^3\ y^{-1}$) and Gulf of Finland (100 $km^3\ y^{-1}$). The remaining 180 $km^3\ y^{-1}$ drains into the Baltic Proper from four major rivers in the south (Oder, Vistula, Nemunas and Daugava rivers) (Voss et al., 2011). The result is a strong gradient in surface water salinity of almost 0 psu in the north to over 20 psu near the Kattegat and Danish Straits. The Baltic Sea itself is composed of a series of deep water basins, and strong stratification occurs between 80 and 100m where fresh water lies above deep saline water masses. These deep saline water masses can experience long periods of stagnation, resulting in persistent anoxic conditions. Water renewal takes place during winter. Its intensity is unpredictable and is strongly dependent upon atmospheric forcing and the position of the salinity gradient within the Belt Sea transition zone (Stigebrandt, 2001).

3. Ecosystem and Environmental Stressors

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. Globally, the Millennium Ecosystem Assessment highlighted that ecosystems around the world have been significantly altered by anthropogenic activity (MEA 2003; 2005). In the Baltic Sea and Skagerrak, eutrophication, over-fishing and intensive use from the transport sector have been the foremost causes of ecosystem deterioration. In the future, global climate change and seawater acidification are likely to constitute real and daunting environmental threats.

3.1. Eutrophication

Human induced eutrophication is a major problem in the Baltic Sea region caused by excessive nitrogen (N) and phosphorus (P) 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 water borne discharges, while about 25% of the nitrogen load comes as atmospheric deposition (Figures 2a-b).

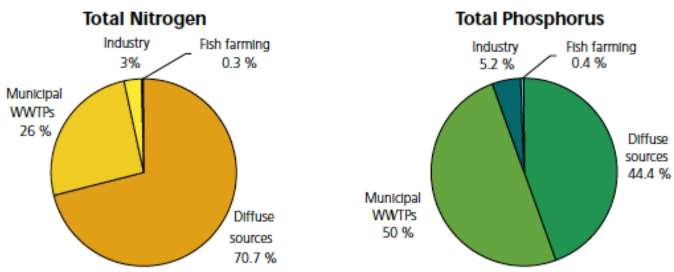


Figure 2a: Proportion of the inputs of total nitrogen and phosphorus by source into surface waters within the catchment area of the Baltic Sea in 2000 (source: HELCOM, 2004). WWTPs = wastewater treatment plants.

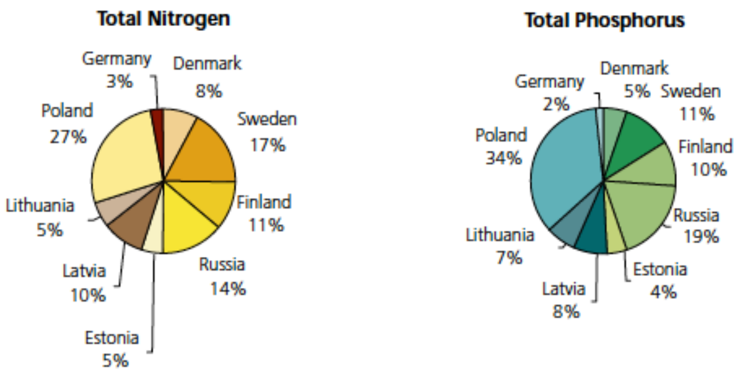


Figure 2b: Average annual proportions of total nitrogen (left) and total phosphorus (right) inputs into the Baltic Sea by HELCOM countries in the period 2001-2006 (source: HELCOM, 2009).

The southern Baltic region is densely populated since centuries and has highly developed agriculture and industries leading to high nitrogen and phosphorus loads along the southern coastline of the Baltic Sea (HELCOM, 2005). This is where coastal eutrophication has its biggest impact. Coastal waters are particularly vulnerable to excessive nutrient loading where increases in the frequency and magnitude of algal blooms occurs, leading to an imbalance in the functioning of the system (Figure 3a).

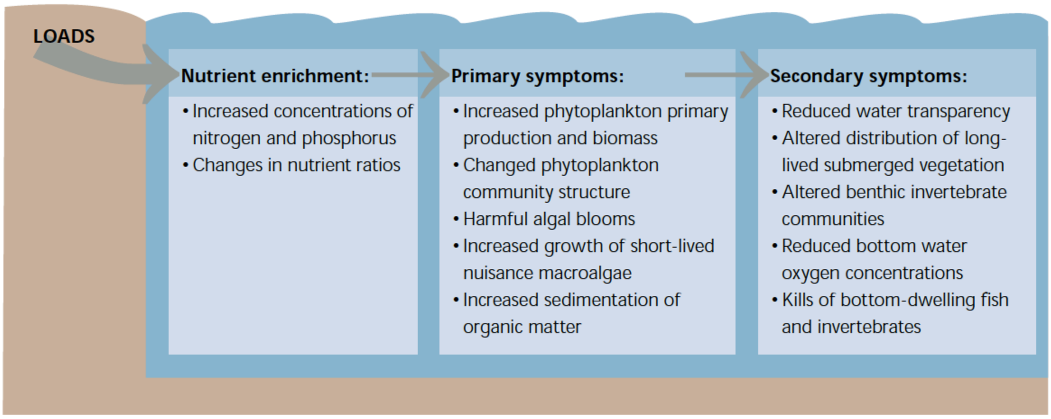


Figure 3a: A simple conceptual model of eutrophication symptoms in the Baltic Sea adapted from Cloern (2001) (source: HELCOM, 2009).

This is manifested as increases in the occurrence of filamentous algae mats, reduced water transparency, excessive production of organic matter, its sedimentation to the seabed, increased sediment oxygen consumption leading to oxygen depletion, anoxic and hypoxic conditions and internal transformations of nutrients in the form of phosphorus regeneration and inhibition of denitrification. Ultimately, the result is an increase in hypoxic sea floors, habitat loss and impaired recruitment success of commercial fish (Garpe, 2008). 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 (HELCOM, 2009a) (Figure 3b).

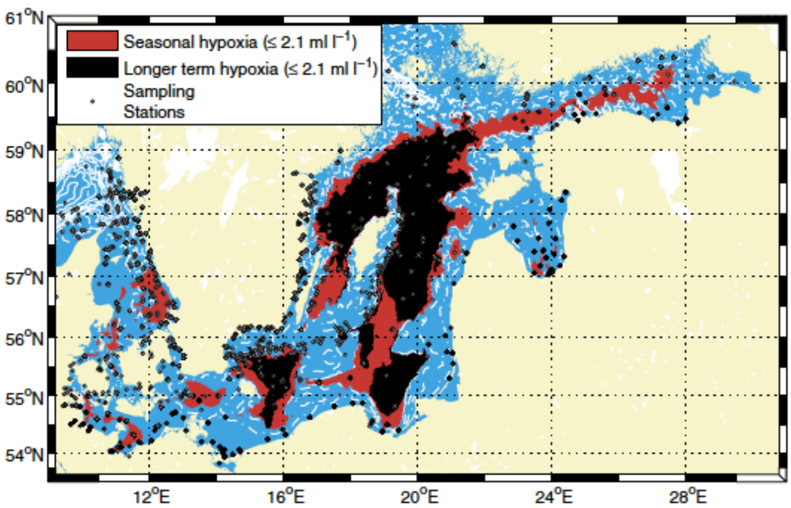


Figure 3b: Extent of seasonal hypoxia (red) and longer-term hypoxia (black) during 2001-2006 (source: HELCOM, 2009)

3.2. Biodiversity and Alien Species

The Baltic Sea is a relatively young sea (ca. 8000 yrs) and its diversity is not yet considered to be fully developed (Garpe, 2008). Species have not had sufficient time to become genetically adapted to the particular environmental conditions of the Baltic Sea and only one species is declared as endemic to the region (*Fucus radicans*). Nevertheless, there is a unique combination of marine and freshwater species that have adapted to the Baltic Sea environment. The impact of brackish water, light limitation, low oxygen and temperature conditions on species diversity is reflected by low biodiversity in the system with very little functional redundancy and many species that can be treated as keystone species (HELCOM, 2009b). The number of marine species decreases towards the north and northeast while the number of freshwater species increases, in line with the salinity gradient. Species are living perpetually under suboptimal conditions, with many at the edge of their physico-chemical tolerance. Many species are genetically distinct from their marine or freshwater source populations, for example, the Baltic cod. Low diversity makes the Baltic Sea ecosystem particularly vulnerable to invasions of alien species which are considered, globally, the second leading cause of biodiversity loss after habitat alteration (UNEP, 2006).

Marine mammals do not have a big presence in the Baltic Sea compared with ocean environments, but there are three important resident populations of seals (i.e. the grey, ringed and harbour seals) and one of whales (i.e. the harbour porpoise) that are found. The grey seal is found in the northern Baltic Proper, the Bothnian Sea and the Gulf of Finland. The ringed seal is found mainly in the Bothnian Bay, the Quark (e.g. between Bothnian Bay and Bothnian Sea), the Gulf of Riga and eastern parts of the Gulf of Finland. The harbour seal is mostly found off southern Sweden and the Danish Straits. The harbour porpoise is mostly found in the southern Baltic Sea, but has also been sighted off the coast of Finland and as far north as the Quark[1].

3.3. Hazardous Substances

The Baltic Sea has been exposed to an extensive use of chemicals from the very beginning of the industrialization of the region in the late 19th century and its marine environment has one of the longest histories of contamination in the world (HELCOM, 2010a). The natural characteristics of the Baltic Sea, namely, its long water residence time, the large catchment area with a population of about 85 million people and a brackish-water environment poor in species predispose the marine environment of the Baltic Sea to contamination and harmful effects caused by hazardous substances.

3.4. Climate Change and Ocean Acidification

The Baltic Sea is currently estimated to be a weak source of CO_2 to atmosphere, -1.05 Tg C yr^{-1} ± 1.71 Tg C yr^{-1} (Kuliński and Pempkowiak, 2011). The extent to which changes to carbon and nutrient fluxes arising from global warming and ocean acidification will modify carbon and nutrient budgets in the future in Baltic Sea, is an open question.

[1] The Baltic Sea Portal, http://www.itameriportaali.fi/en/tietoa/elama/elioryhmat/elaimet/nisakkaat/en_GB/nisakkaat/

The biomes of the northern watersheds have been sinks for organic matter since the last glaciations, however, it is predicted that polar amplification of global warming may defrost and turn these vast areas to carbon and nutrient sources due to enhanced degradation (Graham, 2004). Global warming is projected to lead to pronounced increases in temperature and precipitation in these northern Baltic Sea watersheds (2.6 - 5.1^{o}C and 13 - 33% precipitation) (Graham, 2004) which will alter their entire discharge patterns with significantly higher runoff and a much longer spring flow starting earlier in the season, but with a less pronounced peak flow.In the southern Baltic region, the predictions for the future are different. Here, it is the combination of projected increases in temperature and decreases in salinity (Neumann, 2010) coupled with land use changes and catchment management plans that will determine the extent to which climate change will impact the southern Baltic region (Neumann and Schernewski, 2008).

4. Political Framework and Environmental Management

4.1. Legal Aspects

The political framework underpinning any environmental management for the Baltic Sea region is driven by International, European and national legislation. In terms of environmental assessment of new uses of marine resources in the Baltic Sea region, a number of international conventions, European directives and recommendations are applicable. These include:

- United Nations Convention on the Law of the Sea (UNCLOS)
- United Nations Convention on Biological Diversity (UNEP/CBD)
- United Nations Framework Convention on Climate Change (UNFCCC)
- EU Marine Strategy Framework Directive (2008/56/EC)
- EU Water Framework Directive (2000/60/EC)
- EU Bathing Waters Directive (2006/7/EC)
- EU Urban Waste Waters Directive (91/271/EEC)
- EU Shellfish Directive (2006/113/EC)
- EU Habitats Directive and Natura 2000 (92/43/EEC)
- EU Renewables Directive (2009/28/EC)
- Environmental Impact Assessment (EIA) (2003/35/EC) and Strategic Environmental Assessment (SEA) (2001/42/EC) Directives
- Helsinki Convention for the Protection of the Marine Environment (HELCOM)

While HELCOM falls under the category of recommendations from a legal standpoint, it addresses the entire Baltic Sea area and provides a basis for environmental protection measures by the Baltic Sea countries. Its recommendations may not be binding in terms of international law, but they are of political and moralistic significance and can be considered the minimum standard to which contracting parties should implement national legislation (Czybulka and Krey, 2012). HELCOM recommendations are further supported by the objective of the EU Marine Strategy Framework Directive to establish Good Environmental Status by 2021.

Therein, eleven indicators of good status have been established, as follows:

1. Biological diversity
2. Non-indigenous species
3. Fish & shellfish populations
4. Marine food webs
5. Human-induced eutrophication
6. Seafloor integrity
7. Altering hydrography
8. Contaminants concentrations
9. Contaminants in fish
10. Marine litter
11. Marine noise

These are supported in turn through specific directives such as the Water Framework Directive, Bathing Waters Directive, Urban Waste Water Directive, Shellfish Directive, Habitats Directive including Natura 2000 and Environmental Impact and Strategic Environmental Assessment Directives. Furthermore, the Renewables Directive mandates EU member states to achieve collectively at least 20% of their total energy consumption from renewable sources by 2020.

4.2. Environmental Management

The HELCOM vision for the Baltic Sea is "*a healthy … environment, with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable human economic and social activities*" (HELCOM, 2007).

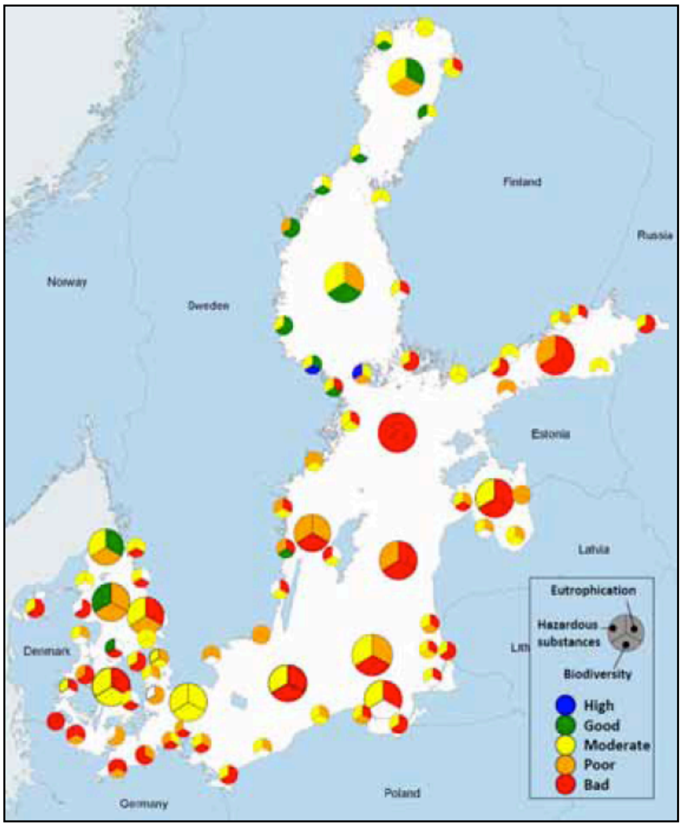
HELCOM Baltic Sea Action Plan has set a number of environmental priorities, including:

1. **Eutrophication:** reduce eutrophication in order to restore ecological balance within the Baltic Sea and to ensure a functioning marine ecosystem.
2. **Hazardous substances:** hazardous substances within the marine environment shall not cause irreversible changes in the functioning of the ecosystem and human.
3. Environmental impacts of **fishery** management and practices: ensure sustainable exploitation of living aquatic resources that provide sustainable economic, environmental and social conditions.
4. Protection and conservation of marine and coastal **biodiversity**: promote a resilient ecosystem that has a sufficient number and connectivity of habitats ensuring healthy species composition and maintained diversity.

HELCOM's Initial Holistic Assessment of the *Ecosystem Health of the Baltic Sea 2003-2007* (HELCOM, 2010b), reports that none of the open basins of the Baltic Sea has an acceptable ecosystem health status at the present time (Figure 4).

The assessment further elaborates: "*the Baltic Sea ecosystem is degraded to such an extent that its capacity to deliver ecosystem goods and services to the people living in the nine coastal states is hampered. The resilience of the marine ecosystem has been undermined by the inputs of* *contaminants from 85 million people living in the catchment area.*

Eutrophication, caused by nutrient pollution, is of major concern in most areas of the Baltic Sea. The Bothnian Bay and the northeastern parts of the Kattegat are the only open-sea areas of the Baltic Sea not affected. The only coastal areas not affected by eutrophication are restricted to the Gulf of Bothnia.



The entire Baltic Sea area is disturbed by hazardous substances and the status was mainly classified as being moderate. Only at very few coastal sites and in the western Kattegat is the water still undisturbed by hazardous substances. Key substances of concern are PCBs, heavy metals, DDT/DDE, TBT, dioxins and brominated substances.

The biodiversity status was classified as being unfavourable in most of the Baltic Sea since only the Bothnia Sea and some coastal areas in the Bothnian Bay were classified as having an acceptable biodiversity status. The results indicate that changes in biodiversity are not restricted to individual species or habitats; the structure of the ecosystem has also been severely disturbed.”

Figure 4: The ‘**eutrophication status**’ from HEAT classifications, the ‘**hazardous substances status**’ from CHASE classifications and the ‘**biodiversity status**’ from BEAT classifications (HELCOM, 2010).

5. SUBMARINER Environmental Assessments

The objective of the environmental assessments of new uses of marine resources within SUBMARINER is to systematically evaluate the impacts a single and/or combined new use of a marine resource may have on the natural environment. An *Ecosystem-Based Management*[2]approach is adopted which draws on relevant issues from existing good practice, guidelines, policy and legal instruments. The aim is to highlight appropriate environmental solutions which address environmental priorities at their source. The intention is not to carry out a full environmental impact assessment but to evaluate the scope of environmental issues that

[2] *Ecosystem-Based Management* is an approach that recognizes the complexity of marine and coastal ecosystems, the connections among them, their links with land and freshwater, and how people interact with them (UNEP, 2011).

are pertinent to the Baltic Sea Region and SUBMARINER new uses, and highlight gaps in information.

5.1. Scope of New Uses

There are nine new uses of marine resources that are explored. These have been identified as having some potential benefit (i.e. environmental, societal, spatial, economic) to the Baltic Sea region (Table 1).

Table 1: 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 BioTech	✔			✔		✓
Wave Energy		✔				✓
Sustainable Fish aquaculture (inc. IMTA)	✓		✓	✔	✔	✓
Offshore Combinations with Wind Parks	✔	✓			✔	✓

✔ = main benefit; ✓ = by-product of main benefit but not sustainable on its own

The scope of each of these new uses is defined for environmental assessment purposes, as follows:

1. **Macroalgae Harvesting**: the scope of macroalgae harvesting includes the harvesting free floating or beach cast macroalgae to support water quality, nutrient recycling and biogas production. Living, attached macroalgae is excluded.
2. **Macroalgae Cultivation**: the scope of macroalgae cultivation includes nearshore cultivation of indigenous macroalgae to support water quality, nutrient recycling, human consumption and biogas production. Alien species are excluded.
3. **Mussel Cultivation**: the scope of mussel cultivation includes the nearshore cultivation of blue and zebra mussels to support water quality and nutrient recycling.
4. **Reed Harvesting**: the scope of reed harvesting includes the removal of reed from coastal reed beds to support nutrient recycling, provide construction material (e.g. thatching and insulation) and produce bioenergy through biogas and biofuel.

5. **Microalgae Cultivation**: the scope of microalgae cultivation is land-based cultivation of microalgae coupled with waste streams (CO_2 flue gas and nutrient-rich waste waters) for biofuel production.
6. **Blue BioTech**: the scope of Blue BioTech includes the extraction of valuable substances produced by marine micro-organisms (such as bacteria, fungi and microalgae) and macro-organisms (such as macro-algae and mussels) to support bioengineering, pharmaceutical, medical, environmental monitoring and cosmetic purposes.
7. **Wave Energy**: the scope of wave energy includes the deployment and operation of a novel wave energy converter device in combination with existing offshore infrastructure (e.g. offshore wind parks, monitoring buoys) as a source of renewable energy.
8. **Sustainable Fish Aquaculture**: the scope of sustainable fish aquaculture includes the development/application of a sustainable aquaculture technology that has little or no environmental impact on the Baltic Sea environment including variations of near-shore Integrated Multi-Trophic Aquaculture (IMTA).
9. **Offshore Combinations with Wind Parks**: the scope of offshore combinations with wind parks includes the possibility of combining individual and/or integrated (IMTA) cultivation activities (e.g. fish aquaculture, macroalgae and mussels) with offshore wind parks.

We note 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 appendix. First, we describe the framework applied to the individual assessments and provide a general overview of the potential impact of new uses on environmental priorities.

5.2. Environmental Priorities and Assessment Framework

The requirements of pertinent EU Directives and HELCOM were used to establish a framework for the SUBMARINER environmental assessments. Consideration is also given to the concept of *Ecosystem Services* (MEA, 2003; Garpe, 2008)[3]. A shortlist of fourteen environmental priorities organised under four broad environmental objectives have been identified as being directly relevant to SUBMARINER. These are described in table 2.

[3] The idea of *Ecosystem Services* was introduced in 2003 by the Millennium Ecosystem Assessment (MEA, 2003), subsequently adapted by the Swedish EPA for the Baltic Sea and Skagerrak (Garpe, 2008) and adopted by HELCOM (2010b). They are defined as *functions and processes through which ecosystems, and the species that they support, sustain and fulfill human life.* They essentially describe the benefits obtained from the environment.

Table 2: Overview of environmental objectives, priorities and related conventions and directives.

Objective	Priority	Purpose	Related Conventions & Directives
Water Quality	Bathing Quality	*Improve bathing water quality*	Marine Strategy Framework Directive (2008/56/EC); Bathing Waters Directive (2006/7/EC); Urban Waste Waters Directive (91/271/EEC)
	Water Transparency	*Improve water transparency*	Marine Strategy Framework Directive (2008/56/EC); Water Framework Directive (2000/60/EC); Shellfish Directive (2006/113/EC)
	Eutrophication	*Decrease eutrophication*	Marine Strategy Framework Directive (2008/56/EC); Water Framework Directive (2000/60/EC); Shellfish Directive (2006/113/EC)
	Biogeochemical Cycling	*Maintain stable biogeochemical cycling*	Marine Strategy Framework Directive (2008/56/EC); Water Framework Directive (2000/60/EC); Shellfish Directive (2006/113/EC)
Habitat / Species Protection	Food Web Dynamics	*Maintain food web dynamics*	United Nations Convention on the Law of the Sea (UNCLOS); United Nations Convention on Biological Diversity (UNEP/CBD); Marine Strategy Framework Directive (2008/56/EC);
	Biodiversity	*Promote biodiversity*	United Nations Convention on Biological Diversity (UNEP/CBD); United Nations Convention on the Law of the Sea (UNCLOS); Marine Strategy Framework Directive (2008/56/EC);
	Benthic Habitats	*Protect benthic habitats*	United Nations Convention on the Law of the Sea (UNCLOS); Habitats Directive and Natura 2000 (92/43/EEC)
	Bird Habitats	*Protect bird habitats*	United Nations Convention on the Law of the Sea (UNCLOS); Habitats Directive and Natura 2000 (92/43/EEC)
	Fisheries	*Protect fish populations*	United Nations Convention on the Law of the Sea (UNCLOS); Habitats Directive and Natura 2000 (92/43/EEC)
	Marine Mammals	*Protect marine mammals*	United Nations Convention on the Law of the Sea (UNCLOS); Habitats Directive and Natura 2000 (92/43/EEC)
	Marine Noise	*Minimise marine noise*	United Nations Convention on the Law of the Sea (UNCLOS); Habitats Directive and Natura 2000 (92/43/EEC)
Coastal Protection	Coastal Morphology	*Protect coastal morphology*	Habitats Directive and Natura 2000 (92/43/EEC)
	Scenery	*Preserve scenery*	United Nations Convention on the Law of the Sea (UNCLOS); Habitats Directive and Natura 2000 (92/43/EEC)
Climate Protection	CO_2 Emissions	*Reduce of CO_2 emissions.*	United Nations Framework Convention on Climate Change (UNFCCC) Renewables Directive (2009/28/EC)

The potential impact that each of the SUBMARINER new uses under consideration may have on these environmental objectives and priorities is assessed and an evaluation is assigned as follows (Table 3):

■ (dark blue)	=	strongly supportive (i.e. makes a major, favourable contribution to the environmental objective and priority);
■ (light blue)	=	moderately supportive (i.e. makes a minor, favourable contribution to the environmental objective and priority);
■ (red)	=	strongly not supportive (i.e. makes a major, unfavourable contribution to the environmental objective and priority);
■ (light red)	=	moderately not supportive (i.e. makes a minor, unfavourable contribution to the environmental objective and priority);
☐	=	neutral (i.e. things stay the same, neither favourable or unfavourable);
?	=	gaps in information, further research needed;
blank	=	not applicable.

For example, a ■symbol assigned to water transparency and eutrophication indicates that the activity strongly supports the improvement of water transparency and a decrease in eutrophication. In other words, it makes a major, favourable contribution to improving water transparency and decreasing eutrophication.

Conversely, a ■ symbol assigned to water quality and eutrophication indicates that the activity is strongly not supportive of the priorities, and makes a major, unfavourable contribution to improving water transparency and decreasing eutrophication.

5.3. Overview of Environmental Assessments

Table 3: Summary of Impact on Environmental Priorities for Various New Uses of Marine Resources in the Baltic Sea Region

	Water Quality				Habitat / Species Protection							Coast Protection		Climate Protection
	Bathing Quality	Water Transparency	Eutrophication	Biogeochemical Cycling	Food Web Dynamics	Biodiversity	Benthic Habitats	Bird Habitats	Fisheries	Marine Mammals	Marine Noise	Coastal Morphology	Scenery	CO_2 Emissions
Macroalgae Harvesting - Beachcast	■	■	■	?/▣	?/◆	?/◆		?/◆				◇	■	▣/◇
Macroalgae Harvesting -Free-floating Mats	■	■	■	?/▣	?/▣/◇	?/▣/◇	?/▣		?/▣/◇		◇/□	◇		▣/◇
Macroalgae Cultivation	▣	▣	■	■/◆/?	■/◆/?	■/◆/?	◆	■	■	◇	◇	■		▣/◇
Mussel Cultivation	■	■	■	◆	◆/?	◆/▣	◆/▣	■	■/◆	◇		▣	◇	
Reed Harvesting		▣/□	▣/□	■/◆/?	■/◆/?	■/◆/?	◆/□	◆/□	◆/□			◇	◇	▣
Microalgae Cultivation		■	■	▣	?	?							◆	■/◆
Blue BioTech	■/?	■/?	■/?	◆/?	□/?	▣/?	▣/?	▣/?	▣/?	▣/?				■
Wave Energy (inc. Wind Park)		□		□			◇	□	◇	◇	◇	□	□	■
Fish Aquaculture (RAS)		◇/□	◇/□			◇		◇	◆	◇				◆
Nearshore IMTAs		◇/□	◇/□	◇	◇	◇	◇	◇	◆	◇			◇	
Offshore Combinations*		▣	■	◇/▣/?	◇/▣/?	◇/▣/?	◇	■/◆/?	■	◇	◇			◇/▣

■ = strongly supportive; ▣ = moderately supportive; ◆ = strongly not supportive; ◇ = moderately not supportive; □ = neutral; ? = gaps in information; blank = not applicable

*Macroalgae cultivation assessment shown here. Refer to individual assessment (section 7.9) for evaluation of impact of other combinations with offshore wind parks, e.g. IMTAs and Mussels.

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7. Appendix: Individual Environmental Assessments

7.1. Macroalgae Harvesting Environmental Assessment

7.2. Macroalgae Cultivation Environmental Assessment

7.3. Mussel Cultivation Environmental Assessment

7.4. Reed Harvesting Environmental Assessment

7.5. Microalgae Cultivation Environmental Assessment

7.6. Blue BioTech Environmental Assessment

7.7. Wave Energy Environmental Assessment

7.8. Sustainable Fish Aquaculture Environmental Assessment

7.9. Offshore Combinations with Wind Parks Environmental Assessment

7.1. Macroalgae Harvesting Environmental Assessment

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Scope

The scope of macroalgae harvesting includes the collection of beach cast and removal of free-floating algal mats to support water quality, nutrient recycling and biogas production. Living, attached macroalgae is excluded as conditions in the Baltic Sea do not support this activity in an environmentally, sustainable way (Blidberg & Gröndahl, 2012).

Overview

Many coastal areas of the Baltic Sea region suffer from chronic periods of excessive macroalgae production as a result of too many nutrient inputs and eutrophication, making it attractive to remove surplus biomass. Moreover, there is an added bonus associated with using the collected biomass to produce biogas. An important consideration though for the environmental assessment of beach cast and free-floating algal mat removal is 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, namely: ***bathing water quality, water transparency, eutrophication, biogeochemical cycles, food web dynamics, biodiversity, benthic and bird habitats, fisheries, coastal protection*** and ***climate protection***. (Table 7.1.1).

Generally, the impacts are similar for collecting beach cast and removing free-floating algal mats, however, there are differences in some of the environmental priorities that are impacted and the degree to which the environmental priorities are impacted. The most serious concerns for beach cast collection are its impact on food web dynamics, biodiversity and bird habitats. In the case of algal mat removal, there are moderate concerns related to its impact on food web dynamics, biodiversity and fisheries, however, depending on the density of the biomass which is removed, the impact of algal mat removal may also be positive on these priorities. The impact of marine noise is also a moderate concern when removing algal mats, and depending on location, the impact on coastal morphology is a moderate concern for both beach cast collection and algal mat removal. Harvesting technology will be key to determining the extent of this impact (Blidberg and Gröndahl, 2012; Werner and Kraan, 2004). The impact on biogeochemical cycling of nutrients is assumed to be favourable in both cases but much is unknown about how exactly this will be altered and the degree to which this is beneficial. Further discussion on the type and extent of these impacts on environmental priorities is provided below.

Table 7.1.1: Overview of macroalgae harvesting impact on environmental objectives and priorities

Environmental Objective	Environmental Priority	Beach Cast	Algal Mats	Comments
Water Quality	Bathing Quality	[dark blue ■]	[dark blue ■]	
	Water Transparency	[dark blue ■]	[dark blue ■]	
	Eutrophication	[dark blue ■]	[dark blue ■]	
	Biogeochemical Cycles	?/[light blue ■]	?/[light blue ■]	
Habitat / Species Protection	Food Web Dynamics	?/[red ■]	?/[light blue ■]/[light red ■]	Depends on density of biomass
	Biodiversity	?/[red ■]	?/[light blue ■]/[light red ■]	Depends on density of biomass
	Benthic Habitats		?/[light blue ■]	Depends on density of biomass
	Bird Habitats	?/[red ■]		Important during overwintering & migration periods
	Fisheries		?/[light blue ■]/[light red ■]	Depends on density of biomass
	Marine Mammals			
	Marine Noise		[light red ■]/□	Depends on technology
Coastal Protection	Coastal Morphology	[light red ■]	[light red ■]	Depends on location
	Scenery	[dark blue ■]		
Climate Protection	CO_2 Emissions	[light blue ■]/[light red ■]	[light blue ■]/[light red ■]	Biogas production/harvest effort

[dark blue ■] = strongly supportive; [light blue ■] = moderately supportive; [red ■] = strongly not supportive; [light red ■] = moderately not supportive; □ = neutral; ? = gaps in information; blank = not applicable

Environmental Priorities

Bathing Quality, Water Transparency, Eutrophication:

The collection of beach cast and removal of free-floating macroalgae can have a positive impact on three aspects of water quality: nutrient loading, heavy metals and organohalogen compounds (mostly algal mats). Together, these impacts all contribute favourably to bathing water quality, water transparency, nutrient recycling and mitigation against eutrophication. The removal of free-floating algal mats can also alleviate the impact of anthropogenic nutrient loading to the Baltic Sea. Nutrients are essential for macroalgae growth but different species vary in their uptake rates and content. Generally, the nitrogen content in macroalgae is around 2-6 % of the algae dry weight (e.g. Pedersen and Borum, 1996; Pedersen and Borum, 1997; Gröndahl et al., 2009) and the phosphorus content is about ten times lower. Nevertheless, the removal of macroalgae biomass will always imply that a certain amount of nutrients will be removed from the water which is favourable in a eutrophic environment, although the benefits will be seen on a local level. Risén and Grondahl et al. (2011) calculated that if all potential macroalgal biomass is collected in the case of Trelleborg, the nitrogen reduction corresponds to approximately 5-15 % of the freshwater runoff input to the area.

Macroalgae are known to accumulate heavy metals (Davis et al., 2000; Villares et al., 2001; Villares et al., 2002; Davis et al., 2003). If macroalgae are removed, the potential harmful substances will be taken out of the system which is another positive effect of the activity, assuming the biomass is used for another purpose, e.g. biogas production. It will be necessary to have proper treatment of material containing problematic substances and further monitoring of the heavy metal concentrations. If the collected material is only moved further up the beach, as could be the case for beach cast, then the problem is just moved from one location to another.

Macroalgae produce a number of organohalogen compounds e.g. polybrominated substances which can be significant in the case of free-floating algal mats. These compounds have a functional significance by protecting the algae from predation and antifouling. It has been shown that the effluents from red algal decaying close to the shore may be harmful to marine organisms in the littoral zone (Eklund et al., 2005). Large quantities of decaying algae may cause such high concentrations of the toxin that it affects the young stages of *Fucus vesiculosus*, a key species in the Baltic Sea which is particularly sensitive to the toxins. Since *Fucus vesiculosus* has two reproduction periods, one in the early summer and one in the autumn, this could be a potential risk for the recruitment of new individuals.

Benthic Habitats, Food Web Dynamics and Biodiversity:

With respect to the collection of beach cast (beach cleaning) and biodiversity, no impact on species diversity was found in macroscopic invertebrates or free-living nematodes when clean and non-cleaned beaches were compared (Malm et al., 2004; Gheskiere et al., 2006).

Thin algal mats function as a shelter to the benthic macrofauna and epibenthic fauna, increasing both biomass and species diversity (Norkko et al., 2000). Accumulations of detached macroalgae in the surf- zone have been shown to be an important source of food for small crustaceans, which are then preyed upon by juvenile fish and larger crustaceans (Orr and Heymans 2011). On the other hand, several scientists have established that dense algal mats close to the shore can be devastating to some organisms living there while others benefit from this new habitat (Norkko and Bonsdorff, 1996ab; Bonsdorff et al., 1997; Norkko et al., 2000; Svensson and Phil, 2001; Troell et al., 2005). Svensson and Phil (2001) showed that the number of species, and the density and biomass of benthic macrofauna are 40-50% lower under mature algal mats. This can be explained by deteriorating oxygen conditions, but also by unsuccessful recruitment of new larvae. Suspension and surface deposit feeders are lost and the community structure will shift to include functional groups such as filter feeders and predators. There is also a shift to species that are more tolerant and opportunistic when algal mats are present (Norkko and Bonsdorff, 1996ab).

Fauna directly associated with macroalgal mats, i.e. those that use algal mats as their habitat, accompany the mats when they are removed and become reduced in number. Indirectly, it may also affect the species richness in the adjacent environment due to the positive or negative effects to organisms on higher trophic levels in the food-web. The lack of studies on biodiversity in this respect makes it difficult to draw any clear conclusions. More research on the impact of macroalgae removal on biodiversity is needed. No studies were found that consider the whole ecosystem when removing macroalgae but it is evident that different organism levels are dependent on each other. This makes it especially important to understand the effect of macroalgae removal on trophodynamics and community structure and know what the thresholds for overharvesting are.

Bird Habitats, Food Web Dynamics and Biodiversity:

Orr and Heymans (2011) reported that beaches without cast macroalgae are relatively barren and lifeless and it is clear that beach cast macroalgae plays a vital role in maintaining coastal biodiversity and functioning. Decomposition of beach cast can supply a vital source of nutrients and particulate organic matter to subtidal and surf-zone communities.Beaches and dunes are also critical habitats for shorebirds and they are sensitive to disturbances, especially during the breeding season and migration (Dugan et al., 2003; Gheskiere et al., 2006; Ince et al., 2007). The organisms in the beach cast and algal mats in the littoral zone are also an important food source for shorebirds, particularly wading birds (Bergendahl 2010; Toxicon AB 2010). The number of birds feeding on these localities is highest during migration periods, i.e. in spring and autumn. These factors should be considered when managing the removal of macroalgae. Collection of beach cast on important bird sites can be avoided or prohibited during overwintering and migration periods. Public beaches used by humans for swimming where the bird life is disturbed anyway may be harvested without any problem (Toxicon AB 2010).

Beach cast often covers the terrestrial flora along the shoreline, with negative effects. However, the algae supply the beach with nutrients and structural material, which may be positive for the same flora. Species richness could therefore be either positively or negatively affected by the collection of beach cast. No studies have been found on this subject from the Baltic Sea or elsewhere. However, some of these localities are protected as Natura 2000 habitat 1210 *Cakiletea maritimae* 2 (i.e. formations of annuals or representatives of annuals and perennials, occupying accumulations of drift material and gravel rich in nitrogenous organic matter) highlighting their ecological importance.

Fisheries:

Removing dense algal mats may indirectly have a positive effect on the recruitment success of commercial fish species, providing more attractive nursery grounds for juvenile species. Shallow soft bottoms, where the algal mats are usually found, are essential habitats for many crustaceans and fish species. Many commercial fishery species, e.g. flatfishes use these areas as nursery and feeding grounds (Troell et al., 2005).

Similar to benthic fauna, fish will also suffer from dense algal mats that prevent fish larval immigration and adult fish migration, alter or reduce food resources, and reduce oxygen levels (Troell et al., 2005). It has further been recorded that algal mats have a negative effect on eggs of herring. Laboratory experiments have shown that juvenile cod actively avoid filamentous algae when offered alternative habitats (Borg et al. 1997), and that algal mats negatively affect their foraging success (Isaksson et al. 1994). Consequently, in areas where filamentous macroalgae dominate, the number of fish species and fish biomass decreases (Pihl et al. 1995). Removal of dense algal mats would thus have a positive effect on fish populations.

Coastal Morphology:

In many places around the Baltic Sea there are problems with coastal erosion making it important to understand the interplay between sediment dynamics, beach cast and free-floating algal mats, and which coastal processes dominate the proposed location for algae removal, for example, erosion, along shore currents, wave energy and sand dunes. Beach cast can contribute to coastal protection by reducing the impact of wave energy, preventing wind induced sand transportation process and supporting the formation of coastal dunes (Falco et al., 2008). Similarly, dense algal mats act as buffers for the coast from energy from storms. Collection of beach cast or removal of algal mats can expose vulnerable coastal areas to erosion and compound erosion problems (Defeo et al., 2009). If the location is particularly susceptible to coastal erosion, then the timing of harvesting is critical. Consideration should be given to the frequency of storms during autumn and winter, making it preferable to harvest during more quiescent periods.

Climate Protection

The collection of beach cast or removal of free-floating algae is more or less a neutral activity with respect to the reduction of CO_2 emissions, although, the type of vehicle and fuel used for collection purposes should be taken into account for a proper greenhouse gas (GHG) balance. A by-product of this activity though is the use of collected biomass for biogas production, which can make a modest contribution towards climate protection and the reduction of CO_2 emissions, provided the production process in itself is carbon neutral.

Knowledge Gaps

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 relationship between offshore, attached, living macroalgae stocks and beach cast macroalgae is needed. 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 removed.
- A better understanding of the effects of harvesting on trophodynamics and community structures of fragile food webs.
- The impact of macroalgae harvesting on the biodiversity of a eutrophic, low biodiversity environment.

Concluding Remarks

The collection of beach cast and removal of free-floating algal mats in a eutrophic environment as means to recycle nutrients and combat eutrophication can have some positive impacts at a local level although the processing of harmful substances which may have accumulated in the biomass needs to be dealt with in a controlled manner. Furthermore, it is important to be mindful of the interplay within the local food web and balance the removal of biomass with the needs of the ecosystem. It is also important to adapt the timing of harvesting to the needs of migratory and overwintering bird communities in addition to ensuring the protection of coastal areas that are vulnerable to erosion.

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7.2. Macroalgae Cultivation Environmental Assessment

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Scope

The scope of macroalgae cultivation includes the nearshore cultivationof indigenous macroalgae to support water quality, nutrient recycling, human consumption and biogas production. Alien species are excluded as they are considered one of the biggest threats to natural biodiversity and ecosystem function.

Overview

The development of commercial macroalgae farms in the Baltic Sea region is in its early stages. There are some initiatives that have started or are planned around the region (Blidberg & Grondahl, 2012) but little is known about the environmental impact of macroalgae cultivation in the Baltic Sea Region. Here we rely on information from studies carried out elsewhere in the world on macroalgae cultivation to identify the potentially relevant issues and environmental priorities. These are ***bathing quality, water transparency, eutrophication, biogeochemical cycles, food web dynamics, biodiversity, benthic and bird habitats, fisheries, marine mammals, marine noise, coastal morphology*** and ***climate change***. (Table 7.2.1).

The most serious concern is the impact on benthic processes and communities directly beneath the area of cultivation. Similar to mussel cultivation, increased sedimentation, decreased oxygen levels and changes in internal nutrient regeneration processes may lead to a deterioration of the benthic habitat and food web dynamics and a loss in biodiversity. This will be particularly true in quiescent environments. Suitable sites for cultivation require good water exchange to ensure sufficient nutrient supply but also low energy such that not too much stress is imposed on the mooring system. Harvesting may have an impact on local benthic communities and on CO_2 emissions depending on the harvest technology that is deployed. The type of vehicle and fuel used for collection purposes in addition to the distance the cultivation site is offshore should be taken into account for a proper greenhouse gas (GHG) balance.

Environmental Priorities

Bathing Quality, Water Transparency, Eutrophication and Biogeochemical Cycling:

Macroalgae cultivation may make a moderately favourable contribution towards bathing quality and water transparency as a result of less nutrients being available for natural algae production. More importantly though is the application of macroalgae cultivation as a remediation measure for eutrophic waters. Adjacent to the cultivation site, water quality is expected to improve as a consequence of excess nutrient uptake and removal. However, directly beneath the cultivation site, eutrophication may be exacerbated and the water quality may deteriorate, especially if the water circulation is low.Changes to the benthic cycling of elements and internal nutrient regeneration processes as a result of oxygen depletion may lead to a deterioration of the benthic environment. There is a need to understand the net balance between nutrient removal in the water column and oxygen depletion in the benthos. Unfavourable impacts on benthic habitats are discussed further below.

Table 7.2.1: Overview of macroalgae cultivation impact on environmental objectives and priorities

Environmental Objective	Environmental Priority	Cultivation	Comments
Water Quality	Bathing Quality	■ (light blue)	
	Water Transparency	■ (light blue)	
	Eutrophication	■ (dark blue)	
	Biogeochemical Cycles	■ (dark blue)/■ (red)/?	Unfavourable for benthos
Habitat / Species Protection	Food Web Dynamics	■ (dark blue)/■ (red)/?	Unfavourable for benthos
	Biodiversity	■ (dark blue)/■ (red)/?	Unfavourable for benthos
	Benthic Habitats	■ (red)	
	Bird Habitats	■ (dark blue)	
	Fisheries	■ (dark blue)	
	Marine Mammals	■ (pink)	
	Marine Noise	■ (pink)	Depends on technology
Coastal Protection	Coastal Morphology	■ (dark blue)	
	Scenery		
Climate Protection	CO_2 Emissions	■ (light blue)/■ (pink)	Biogas production/harvest effort

■ (dark blue) = strongly supportive; ■ (light blue) = moderately supportive; ■ (red) = strongly not supportive; ■ (pink) = moderately not supportive; ☐ = neutral; ? = gaps in information; blank = not applicable

Food Web Dynamics, Biodiversity, Benthic and Fish Habitats:

Macroalgae cultivation may have a favourable impact on food web dynamics and biodiversity within the farm area and in waters adjacent to the cultivation site. Primary production increases, providing a food source for grazers (Engqvist et al., 2000; Kotta et al., 2006) and a substrate for epiphytes and fauna (Kersen et al., 2011). The biodiversity may increase within the algal cultivation area since there will be an increase in suitable habitat for both marine invertebrates and fish. It may also be a source for the spreading of species to other areas. It is possible that an increase food source in a culture will increase grazing of surrounding natural macroalgal populations, for example, by the small crustacean, *Idotea sp*. However, not much is known about the ecological interactions between farmed and natural macroalgal populations. While coastal macroalgae cultivation may compete with natural aquatic plant populations for nutrients and sunlight, this is not an issue in eutrophic waters provided that cultivation sites do not shade existing wild plants from sunlight.

Macroalgae cultivation sites can also provide shelter and a habitat for fish and invertebrates leading to a higher abundance of fish due to increased protection (Ólafsson et al., 1995). As fish populations increase within the macroalgae farm sites, this may also increase the food source for organisms higher in the food web. On the other hand, it may also lead to reduced numbers of major microscopic invertebrates (Ólafsson et al., 1995) possibly as a result of increased predation by benthic feeding fish within a farm area. Decreases in biomass of benthic communities may also be a result of there being less fine particulate organic matter available to sediment fauna due to mechanical disturbance within the farm area (Ólafsson et al., 1995). Bottom living species may be less common below a macroalgal farm and the species richness can be reduced as a result of decomposing algae falling to the bottom increasing sedimentation and leading to decreased oxygen levels and changes in internal nutrient regeneration processes. There may be a deterioration of the benthic habitat and benthic food web dynamics, and a loss in benthic biodiversity. This will be particularly true in quiescent environments.

Bird Habitats:

As for the primary and secondary predators, an increase in fish populations mentioned above is a potential benefit for top predators due to an increase in food sources. Birds eating small invertebrates or fish that inhabit the algae will be positively affected by macroalgae farming.

Marine Mammals:

For cultivation techniques used in other parts of the world, no reports of damage to marine mammals have been found in the literature. Nevertheless, if large-scale macroalgae cultivation is developed in the Baltic Sea, it will be important to take into account any migration routes of marine mammals and their potential to become entangled in a farm site or otherwise disturbed.

Marine Noise:

Sound in the marine environment can disturb both marine mammals and fish (Slabbekoorn et al., 2010). Macroalgae culture does not directly create marine sound, however, peripheral activities such as construction during installation, planting, harvesting, and transport by boat and so on, will cause sounds that could be disturbing for marine organisms. The scale of the sound is not considered to be significant though compared to surrounding sounds from other marine activities.

Coastal Morphology:

Macroalgal farms may modify water movement, absorb energy and provide a form of coastal protection for vulnerable coastlines.

Climate Protection:

Macroalgae use carbon dioxide during photosynthesis and the growth of algae has a favourable impact on climate protection as it does not contribute to increasing green house gases in the atmosphere. Any macroalgal cultivation activities that develop in the Baltic Sea will most probably be too small though to make any significant contribution to the reduction of atmospheric CO_2. Using the biomass to produce biogas can make a modest contribution towards climate protection and the reduction of CO_2 emissions, provided that the production process is in itself carbon neutral. The type of vehicle and fuel used for collection purposes in addition to the distance the cultivation site is offshore should also be taken into account for a proper greenhouse gas (GHG) balance.

Combined Effects

The competition for space with other activities in the Baltic Sea region makes it attractive to consider combining macroalgae cultivation with other activities. For example:

Combine cultivation with fish aquaculture

Integrated multi-trophic aquaculture systems can combine macroalgae cultivation with fish aquaculture as a remediation measure against excess nutrients and waste from fish farms.

Off-shore macroalgal cultivation

Integrating macroalgae activities with existing offshore infrastructure such as wind farms is potentially another attractive solution for optimizing space and taking advantage of existing infrastructure.

Further discussion on combined uses can be found in sections 7.8 Sustainable Fish Aquaculture and 7.9 Offshore Combinations with Wind Parks.

Knowledge Gaps

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 ecological interactions between natural and farmed populations of macroalgae and their surrounding ecosystem.
- A better understanding of the biophysical thresholds beneath farm sites which determine oxygen depletion and benthic habitat deterioration (e.g. minimum circulation, water depth, etc).

Concluding Remarks

Coastal macroalgae cultivation may offer an attractive solution to remediate locally against eutrophication while also adding value by using the biomass for biogas production, human consumption, cosmetics and biotechnology. Careful site selection is important though, if the activity is to be sustainable. There should be no conflict with existing natural populations, there should be a minimum impact on the benthos and where appropriate, other spatial uses should be considered.

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7.3. Mussel Cultivation Environmental Assessment

Acknowledgement

Compiled in cooperation with:

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Anastasija Zaiko, CORPI, Klaipeda University, Lithuania

Scope

The scope of mussel cultivation includes the near shore (shallow water <20m) cultivation of blue and zebra mussel farms to support water quality and nutrient recycling and to provide fodder and fertilizer.

Overview

The blue mussel and the zebra mussel are powerful filter-feeders and are considered keystone species in aquatic ecosystems. The blue mussel is better adapted to the more saline waters of the Baltic (> 4 PSU) while the zebra mussel is better adapted to fresher water environments (< 1 PSU, e.g. Szczecin (Oder) Lagoon and Curonian Lagoon). 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).

Generally, the environmental priorities that are impacted by mussel cultivation in a eutrophic environment are ***bathing water quality, water transparency, eutrophication, biogeochemical cycles, food web dynamics, biodiversity, benthic habitats, fisheries, marine mammals, coastal morphology*** and ***scenery*** (Table 7.3.1).

Cultivation of mussels as a means to remove nutrients in eutrophic environments can have positive impacts on the water quality adjacent to a cultivation site. However, there are also negative impacts on benthic communities and on the biogeochemical cycling of nutrients immediately beneath the cultivation site as a result of increased sedimentation, decreased oxygen levels and internal nutrient regeneration processes (Newell, 2004). 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 under debate (Stadmark and Conley, 2011; Rose et al., 2012; Petersen et al., 2012; Stadmark and Conley, 2012). Mussel cultivation on its own as a means to combat eutrophication is not considered to be an appropriate environmental solution as it does not address the problem of nutrient inputs at their source (Leujak, 2011).Furthermore, most eutrophication hotspots already suffer from anoxia which would be made worse by increased sedimentation processes. Notwithstanding the above, mussel farming as 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/or as fertilizer do show promise (Schernewski et al., 2011; Lindahl, 2011, 2012). Biogas production is not considered an environmentally sustainable option for treating biomass due to the high energy demand associated with harvesting, transportation and biogas production processes yielding a too low net energy balance (Gröndahl et al., 2009). Other issues of lesser concern can arise from site selection and its impact on the local scenery and interference and disturbance to migrating marine mammals. Further discussion on the type and extent of these impacts on environmental priorities is provided below.

Table 7.3.1: Overview of mussel cultivation impact on environmental objectives and priorities

Environmental Objective	Environmental Priority	Mussel Cultivation	Comments
Water Quality	Bathing Quality	■ (strongly supportive)	
	Water Transparency	■ (strongly supportive)	
	Eutrophication	■ (strongly supportive)	
	Biogeochemical Cycles	■ (strongly not supportive)	Beneath the site
Habitat / Species Protection	Food Web Dynamics	■ (strongly not supportive)/?	Phyto–zooplankton interactions
	Biodiversity	■ (strongly not supportive)/■ (moderately supportive)	Benthic communities & anoxia
	Benthic Habitats	■ (strongly not supportive)/■ (moderately supportive)	Anoxia versus shelter, food supply
	Bird Habitats	■ (strongly supportive)	
	Fisheries	■ (strongly supportive)/■ (strongly not supportive)	
	Marine Mammals	■ (moderately not supportive)	Depends on location
	Marine Noise		
Coastal Protection	Coastal Morphology	■ (moderately supportive)	
	Scenery	■ (moderately not supportive)	Depends on setup
Climate Protection	CO_2 Emissions		

■ = strongly supportive; ■ = moderately supportive; ■ = strongly not supportive; ■ = moderately not supportive; ☐ = neutral; ? = gaps in information; blank = not applicable

Environmental Priorities

Bathing Quality, Water Transparency and Eutrophication:

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. Furthermore, increases in secchi depth will increase benthic oxygen production. Mitigation against eutrophication is also expected to occur as a result of nutrient removal.

Biogeochemical Cycling, Food Web Dynamics, Biodiversity and Benthic Habitats:

Below the cultivation site, increased sedimentation of organic matter from faeces and pseudofaeces is expected to increase benthic sediment oxygen uptake leading to local oxygen depletion events (Figure 7.3.1).

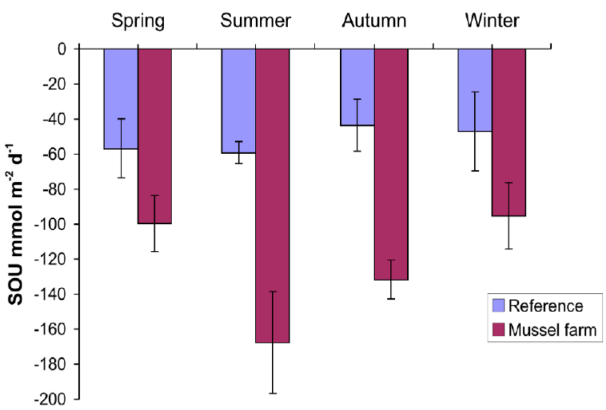

Figure 7.3.1: Impact of mussel cultivation on sedimentation rates (source: J.K. Peterson, 2011)

This may further alter local biogeochemical cycling of nitrogen and phosphorus and lead to internal nutrient regeneration processes in the form of lower rates of denitrification and increased release of phosphorus from sediments. In the longer term, higher incidents of oxygen depletion events in the benthos will enhance sulphide production and may further stimulate oxygen depletion events in the water column which, if left unmanaged, will ultimately have a negative impact on the mussel production (Carlsson et al., 2009). Peterson et al. (2010; 2011) observed a decrease in abundance and biodiversity of benthic communities (Figure 7.3.2) as a result of increased sedimentation and sediment oxygen uptake beneath a mussel cultivation site in the Limfjorden region in Denmark. This was accompanied by a deterioration of food web interactions between phytoplankton and zooplankton communities.

Increased sediment oxygen uptake does not necessarily lead to local oxygen depletion events (Peterson et al., 2012). Carlsson et al. (2009) have made conservative estimates using a simple model and found that increased sediment oxygen uptake underneath farms only causes local anoxia or hypoxia if average water currents in the lower 1m above the bottom were less and 0.82 and 1.63 cms^{-1}, respectively. These water velocities are lower than typical water velocities in most marine environments. Carlsson et al. (2012) have further estimated the significance of nutrient regeneration processes as a result of increased sedimentation and sediment oxygen uptake and found that for the Limfjorden site, there was no significant difference in denitrification inside and outside the mussel farm. Furthermore, the net input of nitrogen from inhibited denitrification processes was less than 2% of the annual nitrogen removal through mussel harvest. It should be noted that these results were carried out in the western, more saline part of the Baltic Sea and are not necessarily directly transferable to the eastern, less saline Baltic Sea and lagoon regions such as the Szczecin and Curonian lagoons. Nevertheless, the results do highlight the importance of selecting an appropriate site, regularly monitoring the site and employing best practices in the farm operation.

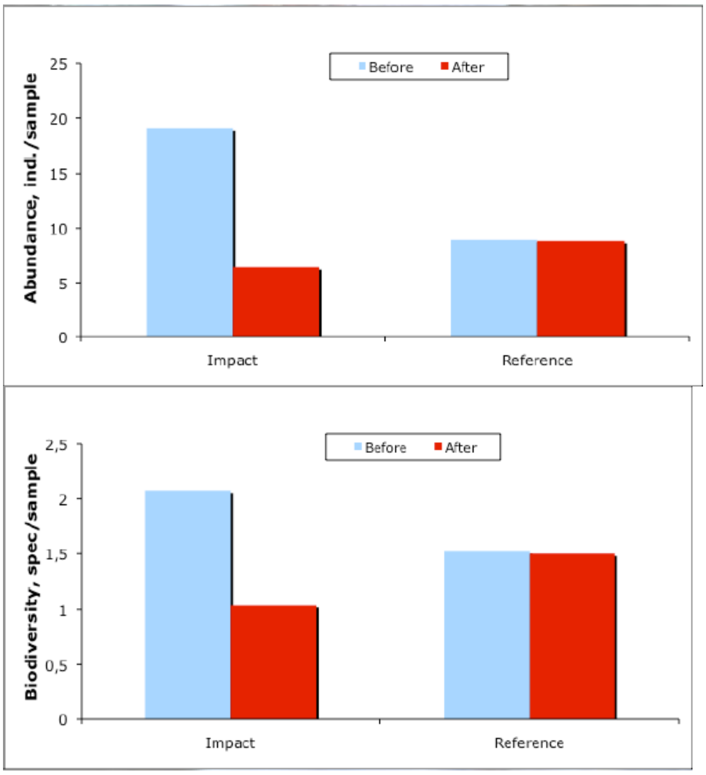

Figure 7.3.2: Impact of mussel cultivation on abundance (top) and biodiversity (bottom) of benthic community (source: J.K. Peterson, 2011).

The impact on benthic biodiversity is not necessarily all unfavourable. Detached mussels may provide a substrate and protection for fish. Moreover, the provision of additional shelter and food supply within or beneath the culture site may in fact increase biodiversity assuming water circulation is above anoxic thresholds mentioned earlier.

Bird Habitats and Fisheries:

Mussel farms may act as floating reefs, which can facilitate an increase in pelagic and surface biodiversity for fish and bird populations.

Marine Mammals:

For cultivation techniques used in other parts of the world, no reports of damage to marine mammals have been found in the literature. Nevertheless, if large-scale mussel cultivation is developed in the Baltic Sea, it will be important to take into account any migration routes of marine mammals and their potential to become entangled in a farm site or otherwise disturbed.

Coastal Morphology and Scenery:

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 though on how the mussel farm is configured on the surface.

Figure 7.3.3: Examples of the varied potential visual impact of mussel farms (left image source: J.K. Peterson, 2011; right image depicts mussel farm from Hållsviken, Trosa, courtesy of Lindahl).

In the future, mussel farms will most likely be lowered subsurface, with negligible impact on the scenery.

Combined Effects

The competition for space with other activities in the Baltic Sea region makes it attractive to consider combining mussel cultivation with other activities. For example:

Combine cultivation with fish aquaculture

Integrated multi-trophic aquaculture systems can combine mussel cultivation with fish aquaculture as a remediation measure against excess nutrients and waste from fish farms.

Off-shore mussel cultivation

Integrating mussel activities with existing offshore infrastructure such as wind farms is potentially another attractive solution for optimizing space and taking advantage of existing infrastructure.

Further discussion on combined uses can be found in sections 7.8 (Sustainable Fish Aquaculture) and 7.9 (Offshore Combinations with Wind Parks).

Knowledge Gaps

- What is the cumulative ecological impact of biomanipulation of bivalve populations?
- What is known about internal transformations in the less saline, eastern Baltic? Consequences for nutrient regeneration and biogeochemical cycling arising from increased sedimentation and sediment oxygen uptake?

Concluding Remarks

It is apparent that mussel cultivation on its own as a means to combat eutrophication is not a viable solution, however, mussel cultivation as 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/or as fertilizer may be an option. The experimental blue and zebra mussel cultivation sites in the Baltic Sea Region (e.g. Swedish coast (Lindahl and Kollberg, 2008; Lindahl and Zaiko, 2012), Kiel Fjord (Krost, 2011), Szczecin Lagoon (Stybel et al., 2009; Schernewski et al., 2011; 2012) and Curonian Lagoon (Lindahl and Zaiko, 2012)) may provide further evidence of this in the future. What is clear is that careful site selection, use of appropriate technology and the implementation of appropriate integrated management measures are key to converging on an environmentally acceptable solution.

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7.4. Reed Harvesting Environmental Assessment

Acknowledgement

Compiled in cooperation with:

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Scope

The scope of reed harvesting includes the removal of reed from coastal reed beds to support nutrient recycling, provide construction material (e.g. thatching and insulation) and produce bioenergy through biogas and biofuel.

Overview

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 for nutrient removal and the application of resource efficiency methods to construction material and production of bioenergy from harvested biomass. A balance between the maintenance of the natural ecosystem services reed beds provide and developing the potential of reed beds to contribute further to ecosystem services is needed.

The environmental priorities that are impacted by harvesting reed in a eutrophic environment are ***water transparency, eutrophication, biogeochemical cycles, food web dynamics, biodiversity, benthic and bird habitats, fisheries, coastal morphology, scenery*** and ***climate protection.*** (Table 7.4.1). 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.

Environmental Priorities

Water Transparency and Eutrophication:

Reed beds can contribute to the overall water quality of an area through the removal of nutrients and post-treatment of waste water. This potential is finite though as accumulated nutrients in the stems need to be removed to make space for new growth which can further accumulate excess nutrients. The extent to which reed beds can improve water quality is dependent on how often and when the reed is harvestedas 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 removalis not an option as it has adverse impacts on such priorities as bird habitats.The potential for nutrient removal is limited (Howard-Williams, 1985) unless the accumulated nutrients are removed and plant shoots harvested (Wathugula et al., 1987). Some studies have shown that regular harvesting neither improves the reed beds and their ability to remove nutrients nor degrades the reed bed; it is analogous to a grassland that is mowed where the impact is neutral (Schilf-Projekt, CAU-Kiel).

Table 7.4.1: 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

Biogeochemical Cycling, Food Web Dynamics, Biodiversity:

Reed beds are intrinsically linked to important biogeochemical processes occurring within the sediments of the coastal reed bed system. They also provide important habitats that maintain and promote biodiversity. The impact disturbing these systems may have on biodiversity and food webs stability is an open question. Reed is a competitor/stress tolerator and mowing can have a positive impact on biodiversity by increasing the competitiveness of other species (Roosaluste, 2007). Burning of reed has been carried out in some locations specifically to increase the competitiveness of other plant species. Furthermore, renewal of the biomass 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.

Benthic Habitats, Bird Habitats and Fisheries:

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 andis the main area of concern for this activity.

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

1. Resident and migratory bird populations and the timing of the breeding season.
2. The type of technology to be used as this is important in determining the impact the activity will have on benthic communities.
3. Resident fish populations and their dependence on reed beds for nursery grounds.

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

Coastal Morphology and Scenery:

Reed beds are a naturally occurring form of coastal protection controlling erosion, stabilizing river banks and reducing wave action along coasts (Möller et al, 2011). Good knowledge of the regional dynamics should be taken into account in addition to the timing of the mowing season to insure that any issues related to coastal protection and storm damage are considered. Changes to coastal morphology may also impact local scenery.

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 is significant is not known. Bioenergy production from reed might contribute at least to some extent to the reduction of CO_2 emissions (and other greenhouse gases (GHGs)) provided the bioenergy production processis in itself carbon neutral.

Combined Effects

Combining reed harvesting with the extraction of curative mud that lies adjacent or beneath the reed bed is under consideration. The removal of mud beneath the reed bed is not recommended as it may also remove important rhizomes and have an unfavourable impact on the reproductive and renewal capacity of the reed bed. Generally though, the curative mud of interest is found adjacent to the reed beds in deeper water depths and the impact on rhizomes is negligible.

Knowledge Gaps

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.

Concluding Remarks

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

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7.5. Microalgae Cultivation Environmental Assessment

Acknowledgement

Compiled in cooperation with:

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Scope

The scope of microalgae cultivation is land-based cultivation of microalgae coupled with waste streams (e.g. CO_2 flue gas and nutrient-rich waste waters) for biofuel production. Alien species are excluded as it is not possible to guarantee their containment in land-based cultures and they are considered one of the biggest threats to natural biodiversity and ecosystem function.

Overview

Given the scope of the microalgae cultivation activity, it is important to consider the scale and full life cycle (e.g. cultivation through to biofuel production) of the activity when assessing the possible impact it may have on the environment. Microalgae cultivation is potentially an attractive environmental solution to supplying biomass energy in the Baltic Sea Region, however, this depends on the feasibility of implementing efficient carbon sequestration and waste water remediation technology to the cultivation process (Carlsson et al., 2007; FAO, 2009). While microalgae production has a high demand for CO_2 and fertilizer, 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 (GHG) emissions than selected terrestrial biofuel crops (corn, canola, and switchgrass) (Clarens et al., 2010). It also significantly outperforms other crops in land use efficiency (Wigmosta et al., 2011).

The environmental priorities that are potentially impacted by cultivating microalgae using land-based technology in a eutrophic environment are ***water transparency, eutrophication, biogeochemical cycles, food web dynamics, biodiversity, scenery*** and ***climate protection***. (Table 7.5.1).

Environmental Priorities

Water Transparency, Eutrophication and Biogeochemical Cycles:

When waste water 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 to the eutrophication status of the area. This will also have a positive impact on the biogeochemical cycling of elements in the water.

Food Web Dynamics and Biodiversity:

Changes to local 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 raceway ponds will have an unfavourable impact on the local scenery, the extent of which depends on the location.

Table 7.5.1: 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 & location
Climate Protection	CO_2 Emissions	■/■	Depends on Net Energy Ratio

■ = strongly supportive; ■ = moderately supportive; ■ = strongly not supportive; ■ = moderately not supportive; ☐ = neutral; ? = gaps in information; blank = not applicable

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 which 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 (Jorquera et al., 2010). 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 realized compared to fossil fuel production with an unfavourable net energy balance (Razon & Tan, 2011).

One study which combines microalgae cultivation and biofuel production with using waste water streams to supply nutrients and flue gas to supply CO_2 (Soratana and Landis, 2011) reports a favourable impact on reduction of CO_2 emissions and eutrophication.

Table 7.5.2: Knowledge gaps, obstacles and suggested solutions

Bottleneck	Main problem	Suggestion for solution
Algae cultivation		
Cultivation technology	Open pond: Large area need Photobioreactor: High construction and operation costs Emissions from construction phase.	Material choices Combination of open pond and PRB
Fertilizer need	Energy consumption of mineral fertilizer production	Use of waste water Reject biomass use from anaerobic digestion
CO2 need	Emissions and costs of the use of pure CO2	CO2 from flue gases
Harvesting and drying technologies	Energy usage	Biofuel production technology choice
Biofuel/biogas production		
Lipid extraction in biodiesel production	Energy consumption	Flue gas use as heating source Intensify biodiesel production with the 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 fertilizer 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 codigestion with nitrogen poor substrate. Use species with high C:N ratio

Knowledge Gaps

With an activity that has cultivation and production processes intrinsically linked, life cycle assessments are helpful in identifying important environmental impacts/issues and where obstacles exist in the process. A number of studies have been carried out which explore the life cycle assessment of microalgae cultivation for biofuel production and identify which processes in the production process are the most demanding energy wise, and hence, where research efforts need to be invested to overcome these obstacles (Seppälä et al., 2012; Table 7.5.2). 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 their 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.

Concluding Remarks

Algae biomass is seen as a promising raw material alternative to first and second generation biofuels, however, many things need to be considered before microalgae cultivation for biofuel production can be realized in an environmentally and economically sustainable way. The main obstacle to overcome is the high energy demand.

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7.6. Blue BioTech Environmental Assessment

Acknowledgement

Compiled in cooperation with:

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Scope

The scope of Blue BioTech includes the extraction of valuable substances produced by marine micro-organisms (such as bacteria, fungi and microalgae) and macro-organisms (such as macro-algae and mussels) to support bioengineering, pharmaceutical, medical, environmental monitoring and cosmetic purposes. The discovery phase of the activity is laboratory basedwith some potential for applications at sea.

Overview

Blue BioTech is a relatively new field that has yet to realise its full potential (EC DG MARE, 2012). Generally, exploration is supported by highly competitive, commercial companies, which means that most of the research and development efforts are not published openly in the literature. This, combined with the pre-development stage of much of the work, make it difficult to assess the scope of the environmental impacts this field may have on a eutrophic environment. Nevertheless, there are some preliminary issues that can be elaborated.

The environmental areas that may be impacted by Blue BioTech in a eutrophic environment are ***water quality, habitat and species protection*** and ***climate protection***. The anticipated impacts are shown in Table 7.6.1 with the understanding that significant knowledge gaps exist for many environmental priorities due to experimental phase of the activity.Further discussion on the type and extent of these impacts on environmental priorities is provided below.

There are currently three areas of concern: The first relates to biodiversity and the disturbance of the biological environment that occurs with the extraction of the species and capture of non-target species. The second concern relates to the proper handling of hazardous chemicals including the disposal of residues and waste e.g. from organic solvents during the production process. This is generally covered by EU regulations such as the directive 98/24/EG (protection of health and security of the employees against hazard by chemical working materials) and related directives, the German "Gefahrstoffverordnung" (www.gesetze-im-internet.de/gefstoffv_2010) and the directive 2004/10/EC (application of the principles of good laboratory practice). The third concern relates to the unknown consequences to habitats and species through the release of bioengineered compounds or bacteria into the marine environment. This will be avoided by considering Good Manufacturing Practice (GMP) considering the Commission Directives 2003/94/EC and 91/412/EEC as well as the GMP Manual (GMP Manual (Up11), Maas & Peither AG – GMP publishing), the directive 2000/54/EC (protection of workers from risks related to exposure to biological agents at work) as well as the directive 2004/35/CE on environmental liability with regard to the prevention and remedying of environmental damage. In case, that the release of genetic modified organisms in the environment is desired e.g. for degradation pollutants, the DIRECTIVE 2001/18/EC on the deliberate release into the environment of genetically modified organismshas to be taken into account.

Table 7.6.1: Overview of Blue BioTech impact on environmental objectives and priorities

Environmental Objective	Environmental Priority	Blue BioTech	Comments
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	■	

■ = strongly supportive; ■ = moderately supportive; ■ = strongly not supportive; ■ = moderately not supportive; □ = neutral; ? = gaps in information; blank = not applicable

There are also some encouraging developments in Blue BioTech related to the protection and management of marine ecosystems (ESF, 2010). One important application is the development of marine bio-sourced compounds that can safely replace toxic anti-fouling or anti-corrosive agents currently used on boats, ships, and submarine installations. In addition, there is the application of bioengineered bacteria for bioremediation purposes following pollution events or the sequestration of terrestrial carbon in marine habitats (www.io-warnemuende.de/atkim-home.html). The development of detection systems on the basis of compounds produced by marine organisms, e.g. microalgal or bacterial toxins, which are harmful to humans as allergens or as contaminants in seafood, such as shellfish, for the monitoring of the Baltic Sea could prevent diseases caused by these toxins (Luckas et al. 2005, Kankaanpää et al., 2009). More 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 (Wargacki et al., 2012) and supplying a renewable energy source. A pilot facility is under development in Chile, however, the environmental impacts of the technology have not been assessed.

Environmental Priorities

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. From the scientific point of view, several approaches ensure the sustainable production of biologically active compounds without negative impact on the Baltic Sea. 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. These microorganisms are not even seen in the environmental sample but need enrichment and cultivation techniques to make them available for laboratory approaches. Therefore, only tiny amounts of the original sample (such as a piece of sponge, coral, sediment or other) are needed. In case of macro-organisms (e.g. macroalgae, mussels) it is possible to cultivate them using aquaculture where environmental damage by harvest from the habitat is avoided. However, in this case, several other environmental impacts should be considered with respect to macroalgae and mussel cultivation (see sections 7.2 Macroalgae Cultivation and 7.3 Mussel Cultivation).

The unknown consequences to habitats and species through the release of bioengineered compounds or bacteria into the marine environment is potentially of greater importance. The need for environmental monitoring and surveillance has been identified as a growth sector which will continue to increase over the coming decades (EU DG MARE, 2012). In support of this, it is essential that marine bio-source compounds and bacteria are developed which can be used safely in the marine environment. Very little is known at this point on their impact of using bioengineered compounds or bacteria in the marine environment and further research and monitoring of these types of applications is required.

Knowledge Gaps

Further research and monitoring is needed on:

- The impact of releasing bioengineered compounds and bacteria into the marine environment on marine habitats and species.
- The impact of using bioengineered bacteria to optimise the fermentation process in the production of ethanol from macroalgae.

Concluding Remarks

It is difficult to assess the full scope of the environmental impacts that the application of Blue BioTech may have on the marine environment as much of the work is still very much experimental. In areas where some concern has already been identified, it will be important to follow through on environmental impact assessments as the field develops further.

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7.7. Wave Energy Environmental Assessment

Acknowledgement

Compiled in cooperation with:

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Scope

The scope of wave energy includes the deployment and operation of a novel wave energy converter device in combination with existing offshore infrastructure (e.g. offshore wind parks, monitoring buoys) in the Baltic Sea Region as a source of renewable energy.

Overview

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. In the case of a standalone deployment, the environmental priorities that are unfavourably impacted are ***bathing water quality, water transparency, biogeochemical cycles, benthic and bird habitats, fisheries, marine mammals, marine noise, coastal morphology*** and ***scenery*** (Table 7.7.1). 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 devicebeing deployed (Muetze and Vining, 2006).

Environmental Priorities

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.

Table 7.7.1: Overview of the impact of deploying and operating a standalone wave device and a combined wave / wind park 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	[red ■]	□	construction
	Eutrophication			
	Biogeochemical Cycles	[red ■]	□	construction
Habitat / Species Protection	Food Web Dynamics			
	Biodiversity			
	Benthic Habitats	[red ■]	[pink ■]	construction & operations
	Bird Habitats	[red ■]	□	construction
	Fisheries	[red ■]	[pink ■]	construction & operations
	Marine Mammals	[red ■]	[pink ■]	construction &operations
	Marine Noise	[red ■]	[pink ■]	construction &operations
Coastal Protection	Coastal Morphology	[pink ■]	□	construction &operations
	Scenery	[pink ■]	□	construction, operations
Climate Protection	CO_2 Emissions	[dark blue ■]	[dark blue ■]	renewable energy

[dark blue ■] = strongly supportive; [light blue ■] = moderately supportive; [red ■] = strongly not supportive; [pink ■] = moderately not supportive; □ = neutral; ? = gaps in information; blank = not applicable

Marine Noise, Marine Mammals and Fisheries:

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 (Blazauskas, 2012).

Physical damage to mammals arising from collision with the wave energy device and mooring system is also a possibility.

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 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.

Knowledge Gaps

Wave energy converter devices are not used anywhere commercially in the world, however, globally, the technology is at an advanced stage of research and development 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 concept of combined deployments is relatively new and at an early stage of development. Nevertheless, additional engineering issues will arise by nature of the combination which need to be taken into account.

Concluding Remarks

While wave energy is an attractive source of renewable energy, the deploymentof a standalone wave energy converter involves considerable disturbance to the local habitat. For standalone deployments, it is important to understand the full wave energy potential of a proposed deployment site first and balance the value in disturbing the habitat against the potential return in renewal energy. For combined wave energy device deployments, the environmental impact is considerably reduced, 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. wind park operations, environmental monitoring buoys, navigation signs, etc).

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7.8. Sustainable Fish Aquaculture Environmental Assessment

Acknowledgement

Compiled in cooperation with:

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Scope

The scope of sustainable fish aquaculture includes the development/application of an aquaculture technology which has little or no environmental impact on the Baltic Sea environment. This translates into the application of fish aquaculture technology which:

- 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,

Overview

There are a number of environmental problems generally associated with open fish aquaculture development that need to be overcome in order to achieve sustainability. These include:

- the negative impact on water quality arising from fish waste effluent,
- interactions with natural populations and the larger ecosystem, and
- the use of unsustainable wild fish populations as the source of fish feed.

There is the potential to minimize some of these environmental concerns through the use of sustainable feed-supply chains and innovative technologythat closes the production cycle, and the application of an ecosystem management approach. For example, *Recirculating Aquaculture Systems* (RAS) use advanced filtration techniques to recycle waste water thus mitigating against the waste effluent issue. These are land-based, closed systems, which exchange less than 10% effluent water with the natural environment. Modern systems with intensified recycling exchange as little as 1-2% effluent water with the natural environment. *Aquaponic Systems* (Aqua) go a step further and close the cycle of water usage. These systems combine RASs with cultivating plants in water (Hydroponics) in a symbiotic environment where waste water from the fish culture is used to feed the plant culture and is thus filtered and re-used by the fish culture. Lastly, adding variations of *Integrated Multi-Trophic Aquaculture*(IMTA) (e.g. macroalgae and mussels) to existing near-shore *Open Net Cage Systems* (Open) can significantly reduce the environmental impact of Open systems through the direct uptake of dissolved nutrients by primary producers (e.g. macroalgae) and of particulate nutrients by suspension feeders (e.g. mussels), and through harvesting, remove the nutrients from the location. Furthermore, using the harvested mussel and macroalgae biomass for fish feed is an indirect reduction of the environmental pressure on wild stocks exploited for fish feed, however technological solutions are still lacking (Holmer, 2010).

The role of fishmeal and fish oil

The nature of aquaculture feeds and feeding regimes plays a major role in determining the degree of environmental impact resulting from aquaculture (Tacon and Forster, 2003; Mente *et al.*, 2006) (see supplement *"Feeding the Fish"*). This is particularly true for open aquaculture production systems (e.g. net cages/pen enclosures placed in rivers, estuaries and open waterbodies, and land-based flow-through tank, raceway and pond production systems) (Black, 2001; Goldburg *et al.,* 2001; Brooks *et al.*, 2002; Lin and Yi, 2003; Piedrahita, 2003) where the use of compound fish feeds increases the environmental pollution resulting from waste effluents. The bulk of dissolved and suspended inorganic and organic matter contained within the effluents is derived from feed inputs, either directly in the form of the end-products of feed digestion and metabolism or from uneaten/wasted feed (Cho and Bureau, 2001), or indirectly through eutrophication and increased natural productivity (Tacon *et al.*, 1995).

These outputs and their environmental impacts will vary depending upon the aquaculture system used (open or closed systems), feed/nutrient and water management operations, and the assimilative capacity of the surrounding aquatic and terrestrial environments (Tacon, 2008; 2009). 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 emerging from the aquaculture facility through water use and effluent discharge. Furthermore, the production of high quality fish aquaculture dependent on compound fish feeds places additional pressure on natural marine fish stocks for reduction to fishmeal and fish oil. These stocks can be contaminated by their natural environment and consequently, there is a further risk of transferring contaminants higher up the food chain.

To put all this into context, the environmental impacts of four different aquaculture technologies are compared (Open Net Cage System (Open), land-based Recirculating Aquaculture Systems (RAS), land-based Aquaponic Systems (Aqua)) and near-shore Integrated Multi-Trophic Aquaculture (IMTA) (Table 7.8.1).

Environmental Priorities

Open Net Cage Systems (Open) are not considered an environmentally appropriate solution to fish aquaculture in the Baltic Sea Region due to the considerable negative environment impacts associated with them. Land-based Aquaponic systems have the potential to be the least disruptive to the Baltic Sea marine environment, but little is known about their large scale impact as commercial activities have yet to be established. Meanwhile, land-based RAS and near-shore IMTA systems do minimize the unfavourable impacts on water quality and habitat protection compared with Open systems. Overall though, it is clear that the use of natural fish stocks as the source of fish feed remains a major issue among all four technologies. ***Providing an***

environmentally sustainable feed supply chain for aquaculture is key to realizing sustainable fish aquaculture (see supplement "Feeding the Fish").

Table 7.8.1: 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); land-based Aquaponic Systems (Aqua); near-shore Integrated Multi-Trophic Aquaculture (IMTA))

Environmental Objective	Environmental Priority	Open	RAS	Aqua	IMTA	Comments
Water Quality	Bathing Quality	■ (red)				
	Water Transparency	■ (red)	■ (pink)/☐		■ (pink)/☐	
	Eutrophication	■ (red)	■ (pink)/☐		■ (pink)/☐	
	Biogeochemical Cycles	■ (red)			■ (pink)	Beneath the site
Habitat / Species Protection	Food Web Dynamics	■ (red)			■ (pink)	Phyto-zooplankton interactions
	Biodiversity	■ (red)	■ (pink)		■ (pink)	Benthos & anoxia
	Benthic Habitats	■ (red)			■ (pink)	Anoxia
	Bird Habitats	■ (red)	■ (pink)		■ (pink)	Natural stocks used for feed
	Fisheries	■ (red)	■ (red)	■ (red)	■ (red)	Natural stocks used for feed
	Marine Mammals	■ (pink)	■ (pink)	■ (pink)/?	■ (pink)	Natural stocks used for feed
	Marine Noise					
Coastal Protection	Coastal Morphology					
	Scenery	■ (red)			■ (pink)	Depends on setup
Climate Protection	CO_2 Emissions		■ (red)	?		Are Aqua systems energy intensive?

■ (dark blue) = strongly supportive; ■ (light blue) = moderately supportive; ■ (red) = strongly not supportive; ■ (pink) = moderately not supportive; ☐ = neutral; ? = gaps in information; blank = not applicable

Bathing Quality, Water Transparency and Eutrophication:

RAS and IMTA systems go a long way in minimizing the impact of pollution from fish waste effluent compared with open systems. However, caution should be exercised when adopting either of these systems as configuration, site selection and scale of operations are important factors in determining their effectiveness.

The point at which a system may be described as a RAS is, to a large extent arbitrary (Piedrahita, 2003). It is therefore essential to have knowledge of the degree to which water is reused and the extent and characteristics of the water treatment processes used, as these relate directly to the impact the treated effluent which is exchanged with the natural environment will have on general water quality (***bathing***, ***transparency*** and ***eutrophication***). While RAS technology typically incorporates intensive treatment of nutrient rich effluent, treatment processes do not result in overall reductions of the polluting constituent in the effluent, but merely a relocation or change in form that still has to be dealt with in terms of disposal (Piedrahita, 2003). The constituents in tank effluents that are of concern include dissolved and particulate organic matter (DOM and POM), total suspended solids (TSS), nitrogen (N) and phosphorus (P). The amount of constituent that remains in the effluent is dependent largely on the species being cultured and their ability to retain nutrients (feed conversion ratio (FCR)). The pathways through which nitrogen and phosphorus leave a recirculation system are different. Phosphorus is mostly captured in solids along with organic matter while nitrogen is primarily released in dissolved form as ammonia and urea (Piedrahita, 2003). For treatment of cultured fish waste effluent to be effective in minimising its impact with the natural environment, processes should include (at a minimum) aeration, oxygenation, solids removal and biofiltration with denitrification. Solids removal traps and separates a high proportion of P and a small proportion of N, while biofiltration transforms dissolved N (ammonia) to nitrate and facilitates denitrification, a process commonly used in waste water treatment. Without the removal of solids and biofiltration processes, the treated effluent that is exchanged with the natural environment will still contain (albeit less) polluting constituents that will have a negative impact on local water quality.

With the installation of macroalgae and mussel based IMTA, site selection is important and optimizing the efficiency of nutrient uptake from waste effluent. IMTA systems are designed to mitigate against excess nutrients resulting from fish waste, but they do not eliminate the problem. As a consequence, the use of IMTA systems is only beneficial in the Baltic Sea Region when deployed to existing net cage systems to reduce their environmental impact. New deployments of net cages as part of an IMTA system will ultimately still add excess nutrients to an overloaded system.

Biodiversity, Benthic, Bird and Fish Habitats and Mammals:

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. There is a need for local knowledge of the prevailing currents in order to assess the full impact on the benthos. 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 (Dempster et al., 2002).

Various chemicals and medicines are used in mariculture which accumulate in the benthic organisms and sediments below the net cages (Costello et al., 2001; Dean et al., 2007). Little is know though on the sensitivity of benthic habitats to these environmental hazards and medicines.

The use of natural fish stocks as a source of fish feed is a major concern on wild fish populations (see supplement *"Feeding the Fish"*). 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.

Climate Protection:

Current operational requirements of an RAS (and possibly Aquaponic systems) are not carbon neutral. Both high energy consumption related to recirculation systems and heating as well as water use are associated with establishing and running a RAS, placing additional demands on climate change related resources that are already under pressure.

Knowledge Gaps

There is little experience with RAS, Aquaponic 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 technology.
- Improving feeds such that higher nutrient fractions are retained by the fish.
- Applying more carbon neutral alternative energy sources to meet high energy demands of running an RAS and possibly Aquaponic systems.
- Monitoring the efficiency of nutrient uptake by IMTA systems.
- Assessing the impact of chemicals and medicines on benthic habitats.

Concluding Remarks

Recirculating Aquaculture Systems (RAS), Aquaponics and adding near-shore IMTAs to existing Open Net Cage Systems are all potentially good candidates for the provision of sustainable fish aquaculture in the Baltic Sea Region, provided that a sustainable feed supply-chain is established, effective treatment processes are implemented and monitored and in the case of RASs (and possibly Aquaponic systems), more carbon-neutral energy sources are used operationally. The establishment of new Open Net Cage Systems as part of an IMTA is not recommended.

Supplement *"Feeding the Fish"*

Aquaculture is the largest overall user of fishmeal and fish oil, currently accounting for around 56% of global use (Hasan and Halwart, 2009) and over 50% of European use (Huntington and Hasan, 2009), with both fishmeal and fish oil being used in large quantities by the salmon and trout industries. Carnivorous or omnivorous fish being raised in an aquaculture system need to consume nutrients from other fish and seafood, just like when they are in their natural habitat. Historically, these nutrients are obtained from small wild-caught fish (e.g. anchovies) that are processed into fishmeal or fish oil.

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 produce (Figure 7.8.1) (Naylor et al., 2000).

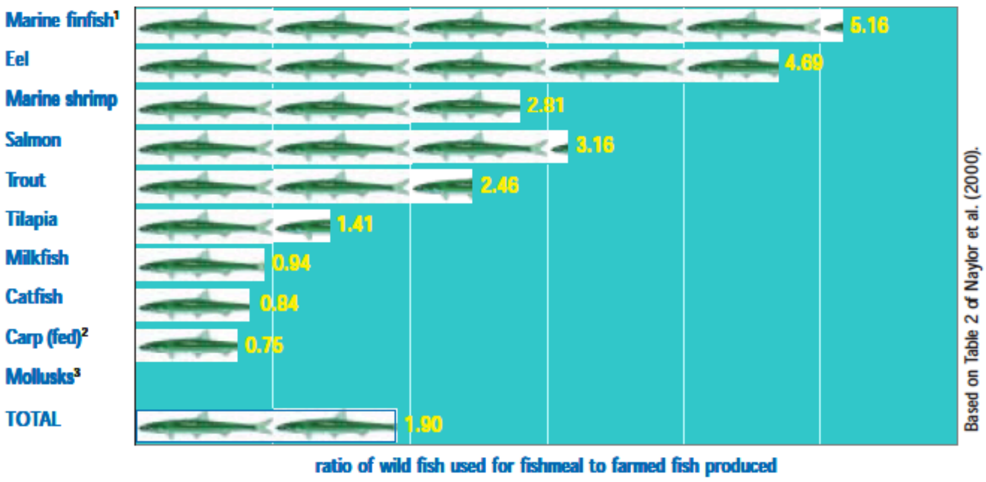

Figure 7.8.1: Ratio of wild fish inputs used in feeds to farmed fish produced for ten types of fish and shellfish most commonly farmed in 1997 (source: Naylor *et al.*, 2001)

Projections concerning the future availability, price and use of fishmeal and fish oil vary widely depending upon the viewpoint and assumptions. On the one hand, fishmeal and fish oil use in aquaculture is expected to decrease long term as a result of rising prices due to limited supplies and increased demand, increasing competition for pelagics for direct human consumption and the desire on the part of consumers for sustainability and a concern for the state of the oceans. On the other hand, industry estimates, and in particular that of the International Fishmeal and Fish Oil Organisation (IFFO), project fishmeal and fish oil use to steadily increase, such that by 2012 aquaculture would use 60 percent of the global supply of fishmeal and 88 percent of the global supply of fish oil (Jackson, 2006).

Nevertheless, the maximum possible yield of fishmeal and fish oil from natural populations is expected to cap at 45 to 50 million metric tons per year, a level that at current growth rates of global marine food production will be reached by 2040 (Olsen et al., 2008)(Figure 7.8.2). Given a combination of the rising cost of fishmeal, the growing demand for a finite resource and growing concern over the “food miles” involved in transporting fishmeal around the world (Huntington, 2004), feed suppliers have focused on the potential to substitute fishmeal and fish oil with plant-based alternatives. This is particularly relevant in the Baltic Sea Region where aquaculture is dominated by salmon and trout farms which are dependent on small pelagics such as anchovies and sardines originating from Chile as their food source!

However, the level of substitution possible is restricted by their lack of essential amino acids (such as lysine, methionine and histidine), which may limit growth at high substitution levels and there are 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).

The preference for the use of fishmeal and fish oil in all forms of diet for cultured fish is based on a favourable amino acid profile providing all the essential amino acids, the availability of unknown growth factors and some micronutrients, easy digestibility, and availability of highly unsaturated fatty acids all of which cannot be synthesized in adequate quantities by most cultured stocks, in particular marine finfish.

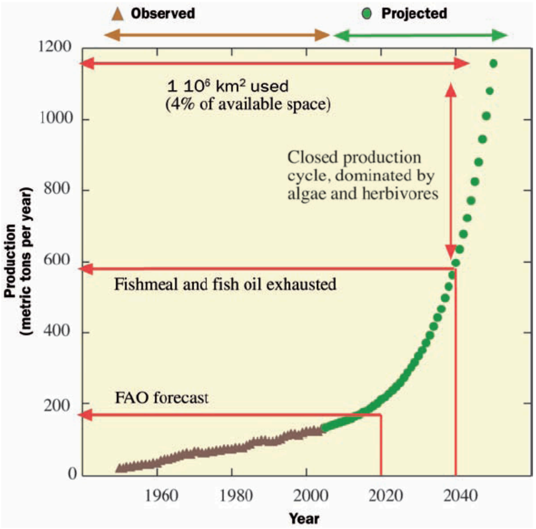

Figure 7.8.2: The time course of observed (brown triangles) and projected (green circles) marine food production and the bottlenecks and changes required to maintain growth (source: Duarte et al, 2009).

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 mariculture rather than harvested from the wild or derived from agriculture, thus closing the production cycle.

In SUBMARINER, harvested blue and zebra mussels as well as macroalgae biomass, all cultured primarily for nutrient recycling and water quality purposes, are being additionally explored as alternative ingredient sources for fish food. Furthermore, the possibility of combining mussels and macroalgae with fish aquaculture in Integrated Multi-Trophic Aquaculture has the potential to improve the overall yield of aquaculture while reducing its environmental impact.

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7.9. Offshore Combinations with Wind Parks Environmental Assessment

Acknowledgement

Compiled in cooperation with:

Pia Bro Christensen, LOKE / Green Center, Denmark

Scope

The scope of offshore combinations with wind parks includes the harvesting of natural fouling agents in the submerged parts of offshore wind park structures, standalone cultivations of macroalgae and/or mussels combined with offshore wind parks, and integrated (IMTA) cultivation activities (e.g. fish aquaculture, macroalgae and mussels) with offshore wind parks. In the Baltic Sea Region, these latter two activities translate into the deployment of open net cage aquaculture systems and / or mussel and macroalgae cultures in water depths between 10 – 30m. (The combination of wave energy devices with offshore wind parks is dealt with in section 7.7 Wave Energy)

Overview

Offshore wind parks are known to support artificial reefs and provide a sanctuary for vulnerable species. The introduction of hard bottom structures onto seabeds which almost exclusively consisted of sandy sediments increases the biodiversity of the habitat and changes the benthic communities from typical infauna communities to hard bottom communities. The local increase in abundance and biomass at wind turbine sites increases the availability of food for fish which in turn leads to an increase in the available food to marine mammals and birds (DONG Energy et al., 2006). Water salinity is the factor that will control the diversity of the community. In the Baltic Sea, the monopiles and shafts of the turbines will typically be dominated by the common mussel, *Mytilus edulis*, due to a lack of efficient predators at low salinities. For safety and inspection purposes though, these submerged structures need to be cleaned regularly, providing an opportunity to removed nutrients and heavy metals from the water and use the harvested biomass for other purposes (e.g. fish feed, biogas). Studies carried out at wind parks near Nysted, Denmark in the Baltic Sea show that a stable, mature epifouling community is established within three years of deployment of the wind turbines (DONG Energy et al., 2006). What is not known is how fast the communities will re-establish themselves after harvesting and what the impact of the loss of biomass is to dependent species, food web dynamics and biodiversity. Regular monitoring of the local ecology is needed.

The establishment of IMTA systems in the Baltic Sea is in its infancy and very little is known about their environmental impacts. It is expected that they can significantly reduce the environmental impact of existing near-shore Open finfish aquaculture systems through the direct uptake of dissolved nutrients by primary producers (e.g. macroalgae) and of particulate nutrients by suspension feeders (e.g. mussels), and through harvesting, remove the nutrients from the location. Furthermore, using the harvested mussel and macroalgae biomass for fish feed is an indirect reduction of the environmental pressure on wild stocks exploited for fish feed, but technological solutions are still lacking in this respect (Homer, 2010). The establishment of new net cage systems as part of an offshore IMTA combination with wind parks raises some additional concerns.

Offshore wind farms can present a hazard for migrating birds and bats. Bats in particular are protected under the Habitats Directive and recent evidence shows that many species of bats migrate south across the Baltic Sea in autumn. Ahlén et al. (2009) observed that 11 of 18 European bat species known to occur in the southern Baltic Sea fly at low elevations over the sea (2 - 10m). However, fatalities occur as they hunt insects attracted to the turbines and the bats are killed by the moving rotor blades on offshore wind farm structures (Rydell et al., 2010). Some studies demonstrate that bat fatalities occur primarily on nights with low wind speed and typically increase immediately before and after the passage of storm fronts. Weather patterns therefore may be a predictor of bat activity and fatalities (Arnett et al. 2008). Unlike birds, there is no long tradition in monitoring bats. They are difficult to monitor and more information is needed on their numbers and migration routes across the Baltic Sea.

Environmental Priorities

Given the relatively shallow water depth (c. 30m) under consideration, many of the environmental benefits that can be realized by moving mariculture offshore (e.g. to water depths >50m (Holmer, 2010)) would only be moderately realized in this scenario, as coupling 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 (see sections 7.2 and 7.3) with some moderation of the unfavourable impacts assumed due to some increase in water depth and location offshore. However, consideration needs to be given to the prevailing climate of the proposed location and the impact of exposure to storms, high winds, and wave activity on the sustainability of the cultures. There is also a considerable increase in the carbon footprint associated with offshore combinations as a result of higher costs associated with harvesting and transport of biomass.

The combination of an offshore finfish, mussel and macroalgae IMTA system is likely to lead to a number of negative impacts on the local environment related to ***water transparency, eutrophication, biodiversity, benthic, bird and fish habitats, mammals and climate protection***. Furthermore, the concern related to the use of sustainable feed supply remains (see section 7.8 Sustainable Fish Aquaculture) until technological solutions to using mussel and macroalgae biomass as feed are realized.

Table 7.9.1: 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; bats
	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; 🔹 = moderately supportive; 🟥 = strongly not supportive; 🔸 = moderately not supportive; □ = neutral; ? = gaps in information; blank = not applicable

Water Transparency and Eutrophication:

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. However, the combination of fish aquaculture IMTA systems with offshore wind parks will most likely have unfavourable impacts on water quality by adding more nutrients to a nutrient-rich environment. While IMTA systems are designed to mitigate against excess nutrients resulting from fish waste, they do not eliminate the problem, and the addition of new IMTA systems will ultimately still add excess nutrients to an overloaded system.

Biodiversity, Benthic, Bird and Fish Habitats and Mammals:

Unfavourable benthic impacts are expected from the deployment of offshore 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 potentially impacting benthic biodiversity. There is a need for local knowledge of the prevailing currents in order to assess the full impact on the benthos. Presumably, the unfavourable impact will be less than in protected near-shore locations due to the increased activity.

However, the increased exposure to the elements at offshore locations increases the risk of escape of cultured fish into natural environment and interactions with wild fish and predators. In addition, wild fish are attracted to cages due to food availability (Dempster et al., 2002).

Various chemicals and medicines are used in mariculture which accumulate in the benthic organisms and sediments below the net cages (Costello et al., 2001; Dean et al., 2007). Little is know though on the sensitivity of benthic habitats to these environmental hazards and medicines.

The use of natural fish stocks as a source of fish feed is a major concern on wild fish populations. 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. This is discussed in more detail in section 7.8 Sustainable Fish Aquaculture.

Climate Protection:

There will be an increase in the carbon footprint as farming moves offshore due to increased harvesting effort and transport costs. This may be compensated for to some extent if the harvested biomass can be used for other (carbon neutralising) purposes.

Knowledge Gaps

There is little experience with harvesting natural fouling agents from wind parks and combining macroalgae, mussel and / or fish aquaculture with offshore wind parks in the Baltic Sea Region. The long term impact of deploying these systems is unknown. Further research would be beneficial in a number of areas. These include:

- 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.
- Assessing the real impact of offshore IMTAs on water quality, i.e. monitoring the efficiency of nutrient uptake by IMTA systems.
- Assessing the potential for water quality remediation using mussel and macroalgae cultivations.
- Assessing the impact of chemicals and medicines on benthic habitats.
- Developing sustainable feed supply chain technology.
- Improving feeds such that higher nutrient fractions are retained by the fish.

Concluding Remarks

The deployment of new open net cages as part of an IMTA system in combination with offshore wind parks is not recommended until more is known about their real impact on water quality and the efficiency of nutrient uptake by colocated mussel and macroalgae cultures, and technological solutions are found to the sustainable feed supply chain issue. Mussel and macroalgae cultures in combination with offshore wind parks are recommended as a water quality remediation effort.

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Improving the Baltic Sea environment and economies: Innovative approaches to the sustainable use of marine resources

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.

Activities

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
- 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

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

Project Duration

October 2010 – December 2013

Project Budget

- ERDF Co-Finance: € 2.8 million
- Partners' contribution: € 0.8 million
- Total Project Budet: € 3.6 million

SUBMARINER

Sustainable Uses of Baltic Marine Resources

www.submariner-project.eu