

# Sustainable Fish Aquaculture

TOPIC COORDINATOR: **Frank Neudörfer** (BioCon Valley  
Mecklenburg-Vorpommern e.V., Germany)

With additional input from **Stephen Knobloch, Gregor Jähne,**  
**Florian Brandtner & Thomas Krey** (University of Rostock,  
Germany) & **Bronwyn Cahill** (Informus GmbH, Germany)





ACCORDING TO THE DEFINITION OF THE FOOD AND AGRICULTURE ORGANIZATION (FAO) OF THE UNITED NATIONS, fish farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated.

Sustainable fish aquaculture translates into the application of a technology that does not pollute the marine environment, does not deplete or permanently damage other marine species or ecosystem components, uses a sustainable feed-supply chain, is not dependent on the use of excessive fossil fuel based energy and complies with the FAO Code of Conduct for Responsible Fisheries and Aquaculture.

## *New Opportunities Based on More Sustainable Technologies*

### Introduction

The aim of the current chapter is to point out the state of the art of fish aquaculture in the Baltic Sea Region with “netcages” as the currently still dominating production technology. It discusses and compares the potential of new technologies and the future possibility to produce fish in a more sustainable manner.

A stagnating fisheries production caused by globally overexploited fish stocks and a rise in demand for seafood have resulted in a spectacular growth in production in the aquaculture sector, which is now the fastest growing food production sector with an average worldwide growth rate of 8.8 % a year since 1980.<sup>1</sup> Since 2000 the contribution of aquaculture products for human consumption has increased from 30 % to nearly

Figure 1: Global production of aquatic species (Data: FAO).

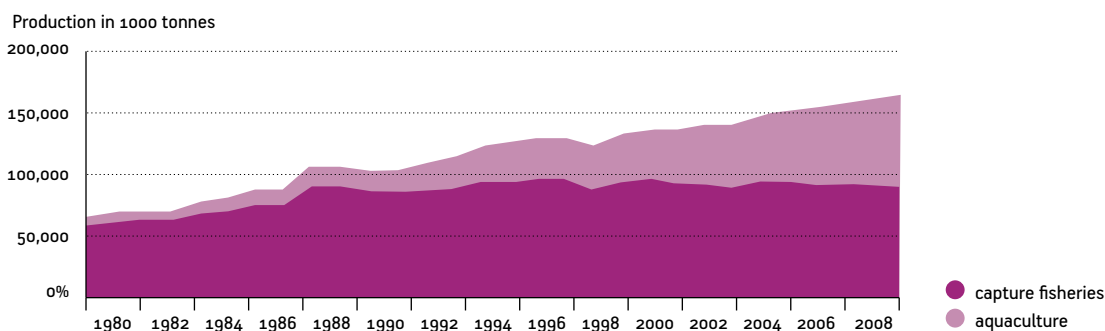
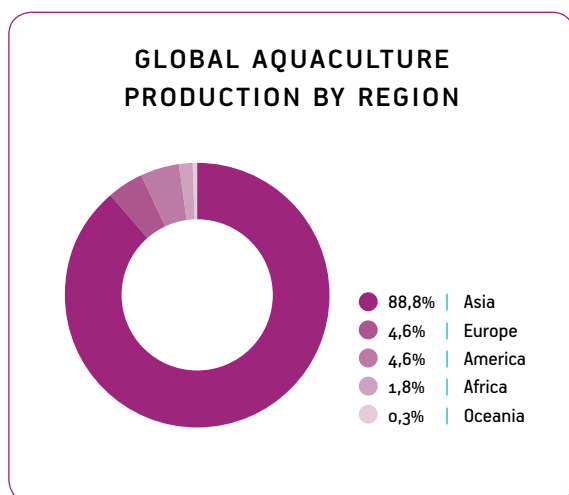


Figure 2: Global aquaculture production by region (Data: FAO).



50 % of global aquatic food production, showing enormous economic opportunities.

Yet compared to Asia and South-America, over-all aquaculture production in the EU has stagnated. Nowadays the EU aquatic food market relies mainly on imports to cover a growing demand.

At the same time, aquaculture raises a number of challenges in regards to the sustainability of production. During the last decade, there has been much debate about what sustainable fish aquaculture is and how it could be realized. From a practical point of view measurable indicators of sustainability in three different areas were determined.

- **Environmental concerns** deal with the quantity of land, water and energy used; water quality, release of alien species and effluents.
- **Economic issues** focused on profitability, market demand and improved feeding efficiency.
- **Sociological interests** centered on employment, local concerns such as residency / ownership and regional sources of inputs (feed, labour, money).<sup>2</sup>

Generally the EU has recognised the important role of aquaculture in terms of food production and its contribution to reducing and eventually eliminating overfishing of wild stocks and has induced significant progress to ensure environmental sustainability, safety and quality of aquaculture production.

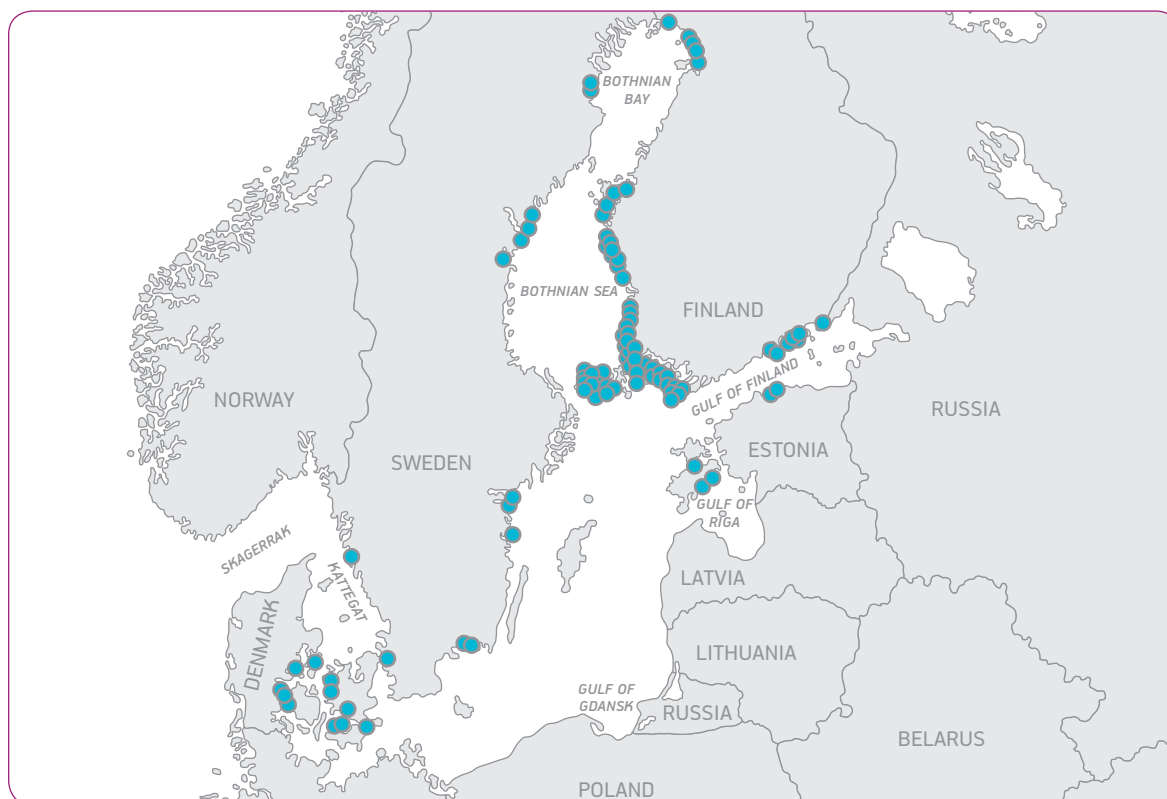
On the global scale, the Baltic Sea Region's marine aquaculture sector has so far only played a very minor role. Nevertheless the Scandinavian countries have a significant tradition in marine aquaculture with a small but stable fish production. The dominating production technology in use is based on "open net cage" systems, which have, in recent years, raised increasing concerns on environmental sustainability.

However, the potential to develop the industry in a more sustainable manner throughout the Baltic Sea Region does exist. Even though natural conditions may not be ideal in the region, the search for methods to decrease import reliance and ways to achieve fish restocking are important motivators for the further development of the sector.

Emerging technology could not only allow for a sustainable fish aquaculture industry in the Baltic Sea, but also permit the introduction of new fish species to reduce imports and increase freshness of the product for consumers. Furthermore, so-called hatcheries, where high water quality standards necessary for fingerlings and fish hatchling production can be assured, may make an important contribution towards restocking of fish within the Baltic Sea.

A dynamic research and technology sector, advanced equipment, trained and qualified entrepreneurs, a solid environmental and health protection legal framework and changing consumer demands towards more eco-friendly products are all strengths which can help further develop this industry. Baltic countries with a longer history in marine fish farming, such as Sweden, Finland and Denmark, could choose to strengthen and increase sustainability of their industry by introducing innovative technology to already existing farms, while at the same time establishing new emerging systems. Other countries where marine fish aquaculture is not yet established due to a lack of suitable sites, may seek to introduce aquaculture systems that are land-based and therefore independent from sites with suitable hydrological water conditions.

Figure 3: Marine and costal fish aquaculture operations in the Baltic Sea Region. Data from wwf.



## Fish Aquaculture in the Baltic Sea Region

### A North-South Divide

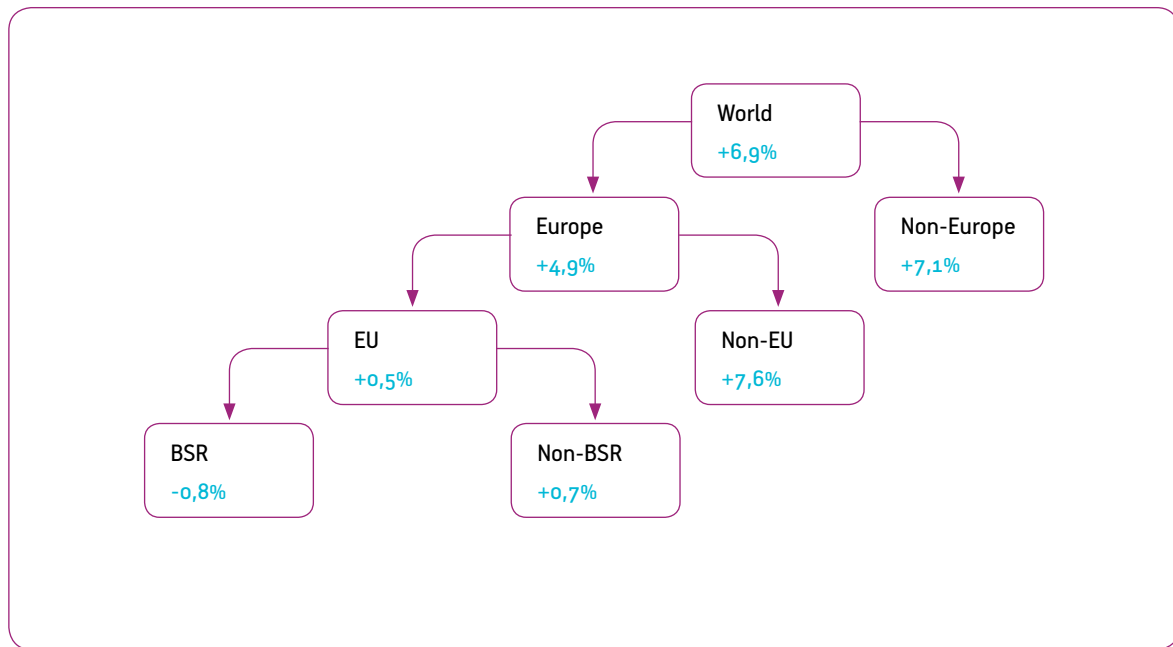
Due to its special characteristics as a brackish inland sea, with a lower water salinity than that of ocean water, the conditions for fish aquaculture in the Baltic Sea are different to those in other marine regions. As a consequence, marine aquaculture in the region is specialised on aquatic species that are adapted to local water conditions. Even within the Baltic Sea the range of salinity varies, being generally higher in the western Baltic Sea than in the eastern parts. This naturally has an effect on the potential fish species that can be reared in marine aquaculture systems in the Baltic Sea Region. Turbot for instance need higher salinities, whereas salmon trout can tolerate a wider range of salinities

found in the Baltic Sea, which is why the region has specialised on production of this particular species. Moreover the availability of sites with suitable hydrological conditions is limited to certain regions, for example in sheltered coasts, gulfs and bays, mainly to be found in Scandinavian countries.

As a consequence of these difficult natural conditions, marine fish aquaculture in the Baltic Sea plays only a minor role in worldwide aquaculture production and is, contrary to global developments, even in decline. With about 27,000 tonnes (2009) of food fish and by-products produced in marine and brackish environments of the Baltic Sea, the region only had a share of under 0.1 % of global aquaculture production. Still, this production was estimated to be worth about € 77 million (2007).<sup>3</sup>

Certain Baltic countries, notably Finland, Sweden and Denmark, have a relatively more developed marine fish farming sector. All three have a

Figure 4: Growth of world aquaculture since 2000, divided by region. (Source: BESTAQ project).



strong tradition of salmon trout (also known as rainbow trout when cultivated in fresh water) farming reaching sometimes as far back to the beginning of the 1900s. During the 1980s and 1990s production declined in these countries but it has been growing again and levelled off in recent years.

Marine fish aquaculture along the German Baltic Sea coast used to be encouraged by former East Germany and prior to reunification, but subsequently the activity disappeared almost entirely. Nowadays only a few fish farms remain in the Kiel Bight and along the coast of Mecklenburg-Vorpommern, producing less than 100 tonnes of salmon trout annually.

Marine fish aquaculture in Poland, Lithuania, Estonia and Latvia is extremely limited and most of it is for restocking measures. There are also little prospects for nearshore aquaculture systems as the coastline is shallow, eutrophic, often polluted by algal blooms and exposed to storms and wave action. Furthermore, extensive ice layers in the winter months, intensive shipping and difficulties protecting and securing net cages situated far from ports create additional challenges.

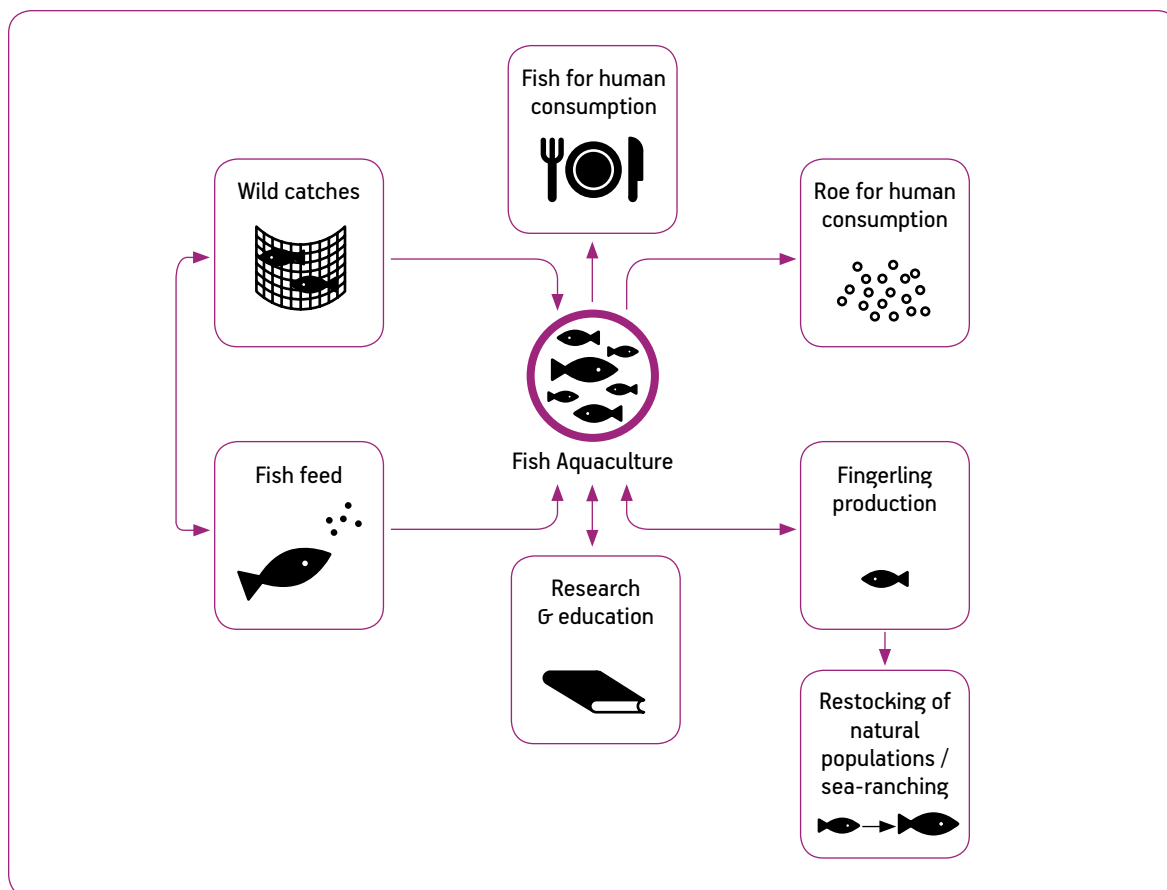
## Open Cages – the predominant cultivation method

The predominant cultivation method used in the Baltic Sea Region is open net cage farming at sea for salmon trout cultivation. This method is used along the coastline of the north-western Baltic Sea, where large parts of the coast are protected by archipelagic islands. Other (more sustainable) methods already in use are land-based saltwater farms (ponds or tanks with water treatment measures) and seawater recirculation systems, also known as Recirculating Aquaculture Systems (RAS).

## DENMARK: SHOWING THE PATH TO SUSTAINABLE PRODUCTION

Since the early 1900s, Denmark has been producing salmon and rainbow trout, originally farmed in freshwater ponds and later on in coastal net cages and land based marine aquaculture units. Strict environmental regulations introduced in the late 1980s including requirements for maximum annual feed allowances, restriction of water intake and maximum amounts of nutrients in outlet waters led to a downward trend in production and the closure of many fish farms. Certain fish farms, however, reacted to these new regulations by strengthening their water treatment practices. They have today developed into model fish farms that use recirculating and water treatment technologies and have increased production while keeping the amount of nutrients in effluent waters low. This trend has also led to the development of a successful niche market for the export of Danish recirculating aquaculture technology.

Figure 5: Applications of fish aquaculture and its interaction with various other practices and resources.



## Applications

### The World's Most Popular Source of Animal Protein

The main product derived from marine aquaculture is obviously farmed fish for human consumption in fresh, frozen or processed form and which can be marketed as whole fish, fillets or convenience products. It is generally accepted that fish is a healthy source of animal protein and its consumption in a well-balanced diet is recommended by the World Health Organisation. In particular, marine fish contain a high amount of omega-3 fatty acids with substantial benefits for heart health. By-products such as roe and fish oil are also sold and often have a high market value.

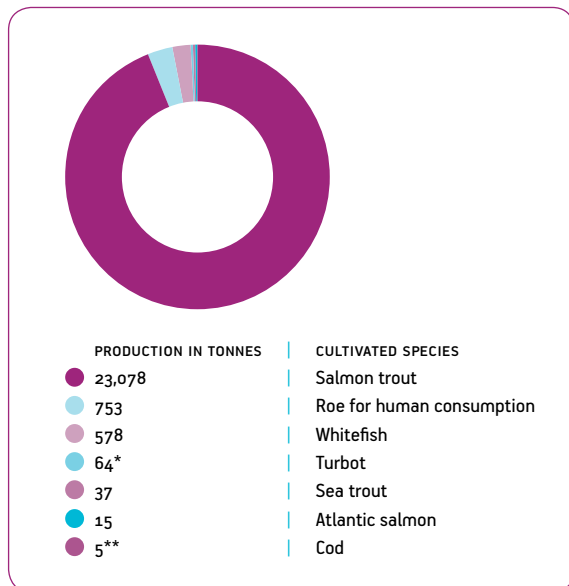
In the Baltic Sea Region, marine fish aquaculture production for human consumption is centred around a few key species, namely salmon trout (overwhelming majority of the volume produced) as well as some whitefish and in small quantities

sea trout, Atlantic salmon, cod and turbot. An essential by-product of salmon and trout aquaculture is roe, which is marketed as 'salmonid caviar' for human consumption.

### An Important Contribution to Restocking

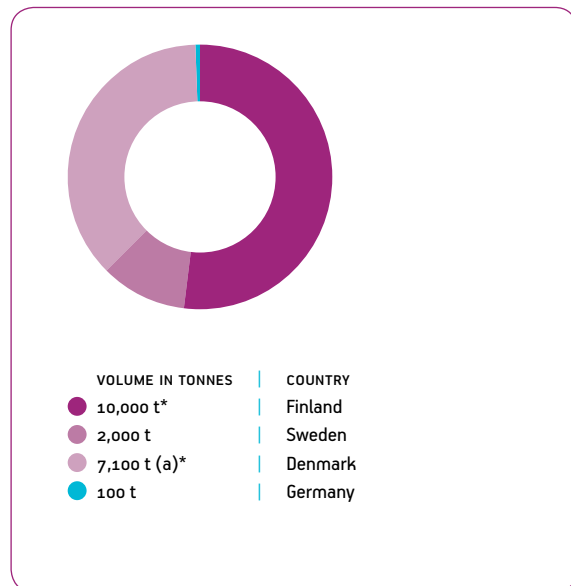
In addition to products for direct human consumption, marine aquaculture within the Baltic Sea plays an important role in closing the reproduction cycle of farmed and wild fish, thus protecting natural fish stocks and preserving biodiversity. Fingerlings and fish hatchlings bred in hatcheries around the Baltic Sea Region are not only used directly in marine aquaculture farms but also for restocking and "sea ranching" purposes. In the latter cases, when the fish are old enough they are freed from the hatchery to mature in the open sea with the goal of improving natural fish stocks and consequently improving the return from capture fishery. Almost all Baltic Sea countries participate in restocking programmes,

Figure 6: Marine aquaculture production in the Baltic Sea in 2009.



\* 2006, \*\* 2008

Figure 7: Overview of net cage production of salmon trout in Finland, Sweden, Denmark and Germany in 2009.



\* Danish salmon trout production in net cages amounted about 10,000 t in 2009, of which 7,100 t can be attributed to Baltic Sea production (Sjælland county).

particularly for Atlantic salmon, sea trout, whitefish and turbot.

The contribution of fish aquaculture to restocking mainly depends on the cultured fish species and the aquaculture system used, its size and its intensity. Species that live naturally in large shoals can be held in high stocking density whereas the opposite may be said for territorial species. For salmon trout, the main produced species in the Baltic Sea,

stocking densities up to 100 kg/m<sup>3</sup> are possible whereas the stocking density for the ongrowing of Atlantic salmon lies at about 20 kg/m<sup>3</sup>. Even within one species the possible stocking density may vary depending on the stage of development and the used aquaculture system. Compared to the ongrowing of Atlantic salmon in net cages, intensive nursery systems for Atlantic salmon (e.g. RAS) can reach up to 50 kg/m<sup>3</sup>.

#### REGIONAL CASES

### AQUACULTURE CONTRIBUTIONS TO RESTOCKING

#### **Finland**

In 2010, the Finnish fish aquaculture sector produced about 65 million fish hatchlings for both further aquaculture rearing and for restocking. The production of different salmon and trout species amounted to about 29 million individuals of which 21 million rainbow trout fingerlings were exclusively produced for food fish production. From the remaining 8 million individuals (Baltic salmon, Landlocked salmon, Brown trout and Sea trout) 79 % were destined for stocking purposes. Of all 485 Finnish fish farms in 2010, 95 farms concentrated exclusively on fry fish production and over 200 farms operated in fry fish as well as food fish production.

#### **Sweden**

The Swedish contribution to restocking amounted in 2009 to about 2.8 million hatchlings which were released into rivers mostly running into the Baltic Sea. Of these 2.8 million, 0.7 million fry were sea trout and 2.1 million salmon.

#### **Denmark**

In 2009, Danish fish aquaculture farms released about 108 tonnes of fish juveniles and 8 tonnes of larger fish for restocking purposes. Of these, about 50 tonnes were produced in freshwater farms and 62 tonnes in re-circulating systems farms. The value of the released fish amounted to DKK 18.3 million (about € 2.5 million). •



## Competence Centres

**Table 1:** Overview on marine fish aquaculture related research institutes in the Baltic Sea Region.

Research institute	Research topics	Contact Person	Website
DTU Aqua, National Institute of Aquatic Resource, Technical University of Denmark	Aquaculture nutrition, growth and welfare, rearing systems and environmental effects	Senior Research Scientist Per Bovbjerg Pedersen	<a href="http://www.aqua.dtu.dk">www.aqua.dtu.dk</a>
Department of Marine Ecology, University of Gothenburg, Sweden	Oyster farming, algal toxins, mussel farming, small-scale aquaculture in developing countries	Aquaculture group leader Susanne Lindegarth	<a href="http://www.bioenv.gu.se/english">www.bioenv.gu.se/english</a>
Finnish Environment Institute (SYKE), Finland	Interaction in coastal waters: a roadmap to sustainable integration of aquaculture and fisheries (COEXIST)	COEXIST project contact at SYKE Juha Grönroos	<a href="http://www.environment.fi">www.environment.fi</a>
Finnish Game and Fisheries Research Institute (FGFRI), Helsinki, Finland	Promoting the aquaculture sector, developing the management of fisheries, selective fish breeding and development of aquaculture technology	Research manager Asmo Honkanen	<a href="http://www.rktl.fi/english">www.rktl.fi/english</a>
Chair of Hydrobiology, Faculty of Biology, University of Latvia	Creation and maintenance of aquaculture collection (organisms of phytoplankton, zooplankton, benthos and fish fauna), algae blooms and toxins	Head of Chair Assoc. Prof. Andris Andrusaitis	<a href="http://www.lu.lv/eng/faculties/fb/structural-units/chair-of-hydrobiology/">www.lu.lv/eng/faculties/fb/structural-units/chair-of-hydrobiology/</a>
University of Kiel / Gesellschaft für Marine Aquakultur mbH, Büsum, Germany	Alternative fish feed, online-controlled culture systems, sustainable development of aquaculture, extractive aquaculture with mussels and algae in the Baltic Sea, water treatment		<a href="http://www.gma-buesum.de">www.gma-buesum.de</a>
Chair of Agriculture and Sea Ranching, faculty of Agricultural and Environmental Sciences, University of Rostock, Germany	Environmental impact of marine aquaculture, fish culture technology, aquatic invertebrates as biological indicator for environmental changes and as diagnosis for aquatic parasites, live feed project	Head of Chair Prof. Dr. Harry Palm	<a href="http://www.auf-aq.uni-rostock.de">www.auf-aq.uni-rostock.de</a>
Institute of Ichthyobiology and Aquaculture Golysz, Polish Academy of Sciences	Fish culture technology, genetic optimization, environmental interaction		<a href="http://www.fish.com.pl/iia_index.html">www.fish.com.pl/iia_index.html</a>
Institute of Animal Science of the Estonian Agricultural University, Estonia	Genetics, selective breeding, fish farming technology, restocking, population ecology and fish health		<a href="http://vl.emu.ee/en/">vl.emu.ee/en/</a>
Division of the Aquaculture and Inland Waters, Fisheries Services, Lithuania	Inland aquaculture	Head of Division Birutė Paliukėnaitė	<a href="http://www.zuv.lt">www.zuv.lt</a>

## Technology

Globally there is a large spectrum of methods and systems for farming aquatic organisms, ranging from high-tech indoor systems and intensive marine net cage aquaculture to small family ponds and rice fields stocked with fish. The differences are mainly due to variations in the culture environment, location and production intensity as well as, of course, the type of species cultivated. In Asia, extensive pond cultures are the predominant aquaculture system, whereas Europe and North America focus on more intensive and often more technology demanding practices.

Increasing competition over coastal area use as well as environmental concerns about unsustainable practices have led to the development of a range of new and innovative methods and technologies in the aquaculture industry. These emerging systems are tied to the most advanced research and are continuously evolving towards a more sustainable development, ensuring the use of best environmental practices and best available techniques.

### Open Water Net Cage Farms

A net cage is a type of enclosure culture unit and involves the holding of aquatic organisms within an enclosed space while a free water exchange is maintained. The cage normally consists of a floating frame, net or meshing materials and a mooring system. It can be placed on different positions within the water column (floating, submerged or submersible).

From a technological perspective, this type of culture system has the disadvantage of having to withstand variable environmental conditions including water temperature changes, ice cover, high waves, storms and changes in water quality such as toxic blooms or low oxygen levels. Thus only a very limited number of suitable sites exist throughout the Baltic Sea Region.

The most important disadvantage, however, are the environmental concerns relating to the pollution generated by the waste effluents as well as

escapes and diseases from fish reared in net cages affecting natural fish populations.

Nevertheless open net cages are currently still the main aquaculture system used in the Baltic Sea Region. Available net cage technology and know-how have assured a low but stable production of fish over the past years. However, mainly the environmental concerns and the lack of suitable space have imposed a natural limit to this type of culture within the region.

New opportunities for the existing net cage aquaculture system may, however, arise from their combination with integrated systems, which decrease the environmental impacts (see IMTA paragraph and Environmental Assessment) or with offshore wind parks, reducing spatial competition and coastal impacts (see “Combinations with Offshore Wind Parks” chapter).

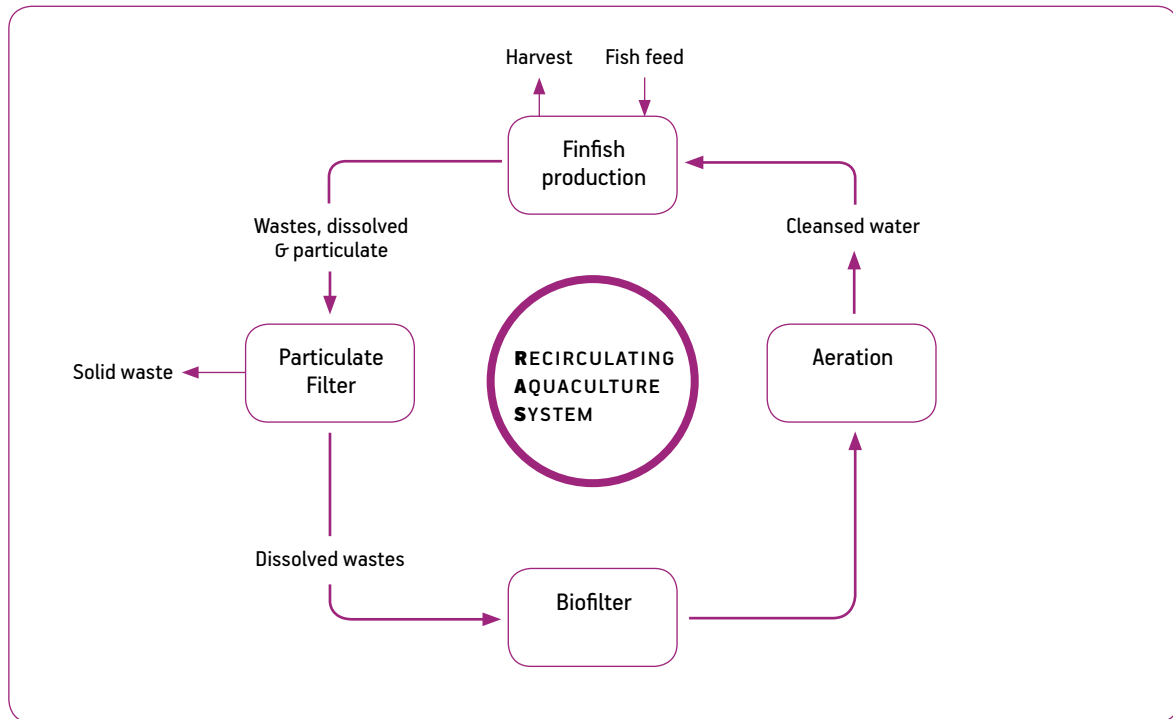
### Recirculating Aquaculture Systems

Recirculating Aquaculture Systems (RAS) are land-based systems using freshwater or saltwater to cultivate fish and other aquatic species in tank and raceway systems. In comparison to traditional aquaculture systems such as open water net cages, modern recirculating systems can transform effluent wastes into non-harmful products with little or no effect on the cultured species. Through a combination of low water exchange rates and advanced mechanical and biological filtration technology, RAS recycle wastewater thus mitigating against waste effluent pollution while using comparatively low water. Modern systems with intensified recycling can even go down to 1–2 % daily water exchange rates.

Modern closed saltwater land-based systems could resolve the problem of coastal site selection as they do not depend on suitable coastal hydrological conditions and also provide the necessary regulation of water parameters.

The main weaknesses of RAS are the high operating costs in terms of energy use for water treatment, as well as high initial investment costs for

Figure 8: Schematic diagram of a Recirculating Aquaculture System (RAS).



plant construction. The use of alternative heating methods such as the combined use of biogas plants could reduce costs and ensure sustainability.

It furthermore takes a considerable amount of time to introduce a new species, as for instance high priced non-endemic fish species, as food product for domestic markets and gain consumer acceptance. In this case a suitable strategy must be established so that new marine fish aquaculture enterprises have a chance to establish aquaculture farms based on producing sea food otherwise imported from non EU countries.

In comparison to net cage farms offshore, RAS have multiple advantages, including the following:

- Effluent water, often containing high nutrient loads, can be treated before being discharged.
- Systems operate independently from seasonal influences and are thus able to produce seafood year round.
- They are isolated from most impacts on natural systems.

- They can be placed in areas where the use of net cages is not possible due to a lack of suitable sites.

However, due to high energy consumption for water circulation and treatment as well as high costs for establishment, the capital investment and operation costs of RAS are comparably high.

RAS are well suited for the production of juvenile fish as the environment needed for rearing can be adapted to the requirements of the individual fish species. The high water quality standards necessary for fry fish production can be assured by water quality control and monitoring mechanisms.

RAS in the Baltic Sea Region are currently mainly used as hatcheries for stock enhancement and restocking programs of endemic fish species. However, some commercial RAS for food fish production do exist in Germany and the Danish North Sea coast, and mostly produce high priced fish species such as turbot or Atlantic salmon in order to cover high investment costs.

Figure 9: Land-based aquaculture installation in Pinnow, Germany.



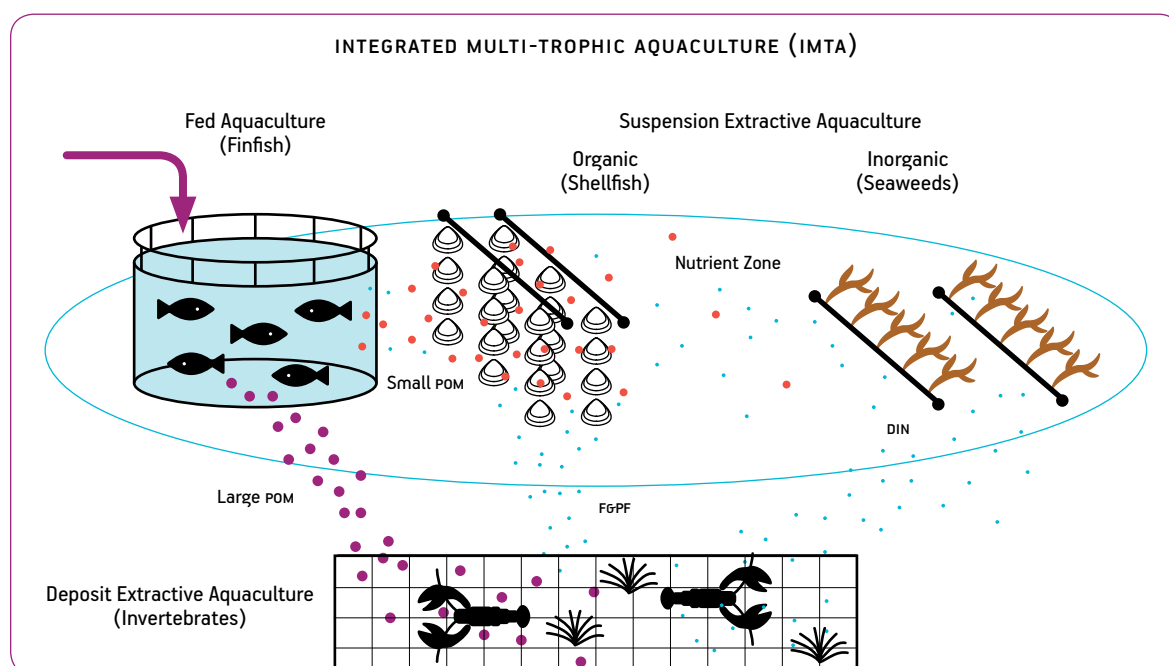
## Integrated Multi-Trophic Systems

Another system that has gone beyond the experimental scale is Integrated Multi-Trophic Aquaculture (IMTA), either in open water or land based systems. IMTA constitutes an advancement of tradi-

tional farming systems in its incorporation of species from different trophic positions or nutritional levels into the same system, so that each organism profits from the other. One example of IMTA is the combination of fish culture with macroalgae and invertebrate culture. Invertebrates and seaweeds filter and absorb the nutrients from the fish operations. Then, not only the cultured fish can be sold, but also the algae and mussels, which can be used as food for human consumption or as feed, fertilizers and for other applications. This method reduces the environmental impact of aquaculture and simultaneously increases profitability.

Adding variations of IMTA to existing near-shore open net cage systems can significantly reduce their environmental impact through the direct uptake of dissolved nutrients by primary producers (e.g. macroalgae) and particulate nutrients by filter feeders (e.g. mussels), and through harvesting, remove the nutrients from the location<sup>4</sup>. Furthermore, using the harvested mussel and macroalgae biomass for fish

Figure 10: Conceptual diagram of an Integrated Multi-Trophic Aquaculture (IMTA) system (based on Chopin, 2011<sup>5</sup>) (POM: particulate organic matter; DIN: dissolved inorganic nutrients; F&PF: faeces & pseudo faeces).



feed is an indirect reduction of the environmental pressure on wild stocks exploited for fish feed.

Worldwide, however, only a few countries have IMTA systems near a commercial scale like Canada, Chile, China and Scotland. In Southern Europe, France, Portugal and Spain have ongoing research projects related to IMTA. Some Scandinavian countries are making groundwork on this field, esp. Norway.

In order to promote the expansion of IMTA in the Baltic Sea Region more knowledge has to be generated on the selection of the right species appropriate to the habitat. Suitable species for IMTA in the Baltic Sea include blue mussel (*Mytilus edulis*) and zebra mussel (*Dreissena polymorpha*) as filter feeders and sea beech (*Delesseria sanguinea*) and sugar kelp (*Saccharina latissima*) as macroalgae components.

In a recent publication on IMTAs and their possibilities of expansion, the authors conclude that IMTA is the best option for a sustainable aquaculture industry: It is environmentally responsible, economically profitable and more socially acceptable than other systems<sup>6</sup>.

Nevertheless it has to be noted that these systems are currently mainly in visionary stage for the Baltic Sea Region as numerous actions are still necessary in order to make the introduction of such technology interesting and feasible for commercial aquaculture companies:

- Implementing appropriate R&D projects
- Establishing the economic and environmental value of IMTA systems
- Selecting (native) species appropriate to the habitat and available technologies
- Selecting species according to the environmental conditions
- Promoting effective government legislation / regulations
- Commercialization of IMTA products

## Environmental Assessment

There are a number of environmental problems generally associated with aquaculture development that need to be overcome in order to achieve sustainability. These include a negative impact on water quality arising from fish waste effluent, the interactions with natural populations and the larger ecosystem, and the use of unsustainable wild fish populations as the source of fish feed.

There is, however, the potential to minimise some of these environmental concerns through the use of innovative technologies, sustainable feed supply chains and the application of an ecosystem management approach. Recirculating Aquaculture Systems or the addition of Integrated Multi-Trophic Aquaculture to existing open net cages are examples of advancements in the field that can significantly reduce environmental impacts through water efficiencies, wastewater recycling and direct uptake of dissolved nutrients. However, existing knowledge gaps must first be overcome in order to successfully implement IMTA concepts with open net cage systems.

## Water Quality

The nature and regimes of aquaculture feeding play a major role in determining the degree of environmental impact, particularly for open water net cage aquaculture production systems, where the use of compound fish feeds increases the environmental pollution resulting from waste effluents.<sup>7, 8, 9, 10, 11, 12, 13</sup> The bulk of dissolved and suspended inorganic and organic matter contained within the effluents is derived from feed inputs, either directly as the end-products of feed digestion or from uneaten feed,<sup>14</sup> or indirectly through eutrophication and increased natural productivity.<sup>15</sup> In general, the greater the intensity and scale of production, the greater the nutrient inputs required and the consequent risk of potential negative environmental impacts.

RAS and IMTA systems go a long way in minimising the impact of pollution from fish waste effluent compared with open water net cage systems.

**Table 2:** Overview of the different impacts of 4 aquaculture technologies on environmental objectives and priorities (i.e. Open Net Cage System (Open); land-based Recirculating Aquaculture Systems (RAS); near-shore Integrated Multi-Trophic Aquaculture (IMTA)).

Environmental Objective	Environmental Priority	Open	RAS	IMTA	Comments
Water quality	Bathing quality	●			
	Water transparency	●	●○	●○	
	Eutrophication	●	●○	●○	
	Biogeochemical cycles	●		●	Beneath the site
Habitat / Species protection	Food web dynamics	●		●	Phyto-zooplankton interactions
	Biodiversity	●	●	●	Benthos & anoxia
	Benthic habitats	●		●	Anoxia
	Bird habitats	●	●	●	Natural stocks used for feed
	Fisheries	●	●	●	Natural stocks used for feed
	Marine mammals	●	●	●	Natural stocks used for feed
	Marine noise				
Coastal protection	Coastal morphology				
	Scenery	●		●	Depends on setup
Climate protection	CO <sub>2</sub> Emissions		●		Are Aqua systems energy intensive?

●	strongly supportive	○	neutral
●	moderately supportive	?	gaps in information;
●	strongly not supportive	blank	not applicable
●	moderately not supportive		

However, caution should be exercised in adopting either of these systems as configuration, site selection and scale of operations are important factors in determining their effectiveness.

For RAS, the degree to which water is reused and the extent and characteristics of the water treatment processes used will directly relate to the impact of the treated effluent on the natural environment. Removal processes should include (at a minimum) aeration, oxygenation, solids removal and biofiltration with denitrification. Also, the polluting constituents removed from the effluent (e.g. dissolved

and particulate organic matter, suspended solids, nitrogen, phosphorus) still have to be properly dealt with in terms of disposal.<sup>13</sup>

## Habitat / Species Protection

Unfavourable benthic impacts are expected from the deployment of IMTAs as a result of rapidly sinking rates of feed and faecal pellets, and organic enrichment of the sediments due to increased sedimentation. Shading of the local ecosystem is expected and interactions with wild fish and predators are also likely as wild fish are attracted to cages due to

food availability.<sup>21</sup> Furthermore, various chemicals and medicines are used in marine fish aquaculture which accumulate in the benthic organisms and sediments below the net cages.<sup>24, 25</sup> Little is known though on the sensitivity of benthic habitats to these environmental hazards and medicines. There is a need for local knowledge of the prevailing currents in order to assess the full impact on the benthos.

Overall, the use of wild fish stocks as a source of fish feed remains a major issue for all aquaculture technologies (see “Additional point”). Furthermore, these natural stocks may be contaminated by their natural environment and there is a further risk of transferring contaminants higher up the food chain.

Providing an environmentally sustainable feed supply chain for aquaculture is key to realising sustainable fish aquaculture. The removal of large quantities of fish species from marine ecosystems has potentially ecosystem and biodiversity impacts on other dependent fish species, birds and mammals.

On balance, global aquaculture production still adds to world fish demand. The future challenge for a further successful development of the aquaculture will be to minimize the natural fish supplies for feed (Natura 2000).

#### ADDITIONAL POINT

##### FEEDING THE FISH

Carnivorous or omnivorous fish raised in an aquaculture systems need to consume nutrients from other fish and seafood, just as in their natural habitat. These nutrients are obtained from small wild-caught fish (e.g. anchovies) that are processed into fishmeal or fish oil. Consequently, aquaculture is the largest overall user of fishmeal and fish oil, currently accounting for around 56 % of global use<sup>16</sup> and over 50 % of European use,<sup>17</sup> particularly in the salmon and trout industries. As a result, one of the major challenges facing sustainable aquaculture development is the procurement of feed for non-herbivorous fish from sustainable sources. To put this into context, it takes more fish biomass to raise some farmed species than those species actually produce.<sup>18</sup>

Projections concerning the future availability, price and use of fishmeal and fish oil vary widely, with some expecting their use to decrease in the long term as a result of rising prices due to limited supplies and increased demand, while others, in particular those of the International Fishmeal and Fish Oil Organisation (IFFO), project fishmeal and fish oil use to steadily increase. Already in 2012, aquaculture is projected to use 60 % of the global supply of fishmeal and 88 % of the global supply of fish oil.<sup>20</sup> Nevertheless, the maximum possible yield of fishmeal and fish oil from natural populations is expected to cap at 45 to 50 million metric tonnes per year, a level that at current growth rates of global marine food production will be reached by 2040.<sup>21</sup>

Given the combination of the rising cost of fishmeal, the growing demand for a finite resource and the growing concern over the “food miles” involved in transporting fishmeal around the world,<sup>22</sup> feed suppliers have focused on the potential

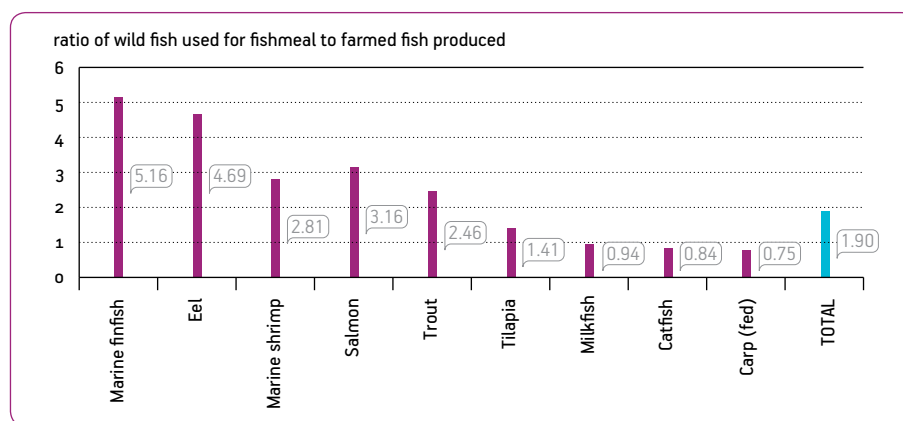




to substitute fishmeal and fish oil with plant-based alternatives. However, the level of substitution possible is restricted by their lack of some essential amino acids which may limit growth. There are also concerns related to the sustainability of using plant-based alternatives for feed as it is dependent on agriculture and raises issues related to freshwater availability and land use (i.e. more clearance of rain-forests). In the SUBMARINER project, harvested blue and zebra mussels as well as macroalgae biomass, all cultured primarily for nutrient recycling and water quality improvement purposes, are being additionally explored as alternative ingredient sources for fish food.

It is clear that there are a number of obstacles that must be overcome if the feed supply chain is to become more sustainable. The food required to feed marine animals should be produced by marine aquaculture rather than harvested from the wild or derived from agriculture, thus closing the production cycle. •

**Figure 11:** Ratio of wild fish inputs used in feed to farmed fish produced for ten types of fish and shellfish most commonly farmed in 1997. Based on Naylor et al., 2001.<sup>19</sup>



## Climate Protection

Current operational requirements of an RAS are not carbon neutral. Both high energy consumption and water use are associated with establishing and running a RAS.

## Socioeconomic Aspects

The total aquaculture production of the Baltic Sea Region countries including freshwater and marine species was worth € 370 million in 2007. The production based alone on saltwater environments in

the Baltic Sea was estimated to be worth € 77 million in the same time period.

The most important factors affecting economic performance of the Baltic Sea Region's marine aquaculture sector are

- Heavy global competition with imports of farmed and wild caught species from other parts of the world;
- Strong demand for high quality and high value fish in Europe;
- Increasing costs of fish meal and fish oil for fish feed;



- Access to sites, licences and waste disposal; and
- Further development and implementation of innovative farming practises and technology to increase sustainability and decrease production costs.

## Sustainability – a cost driver?

Even though economic considerations vary by type of system and intensity of production, most modern farms have in common that they are capital intensive businesses. The capital costs of an aquaculture business are mainly composed of the physical structures, but also costs of licenses, permits and legal costs involved in starting up a new business.

Compared to open water net cage farms, land based recirculating systems are not only more complex in their construction but can also require considerably more capital investment. Apart from the costs for physical structures required to operate tanks and water treatment, costs for land and buildings must be taken into account. For comparison: A **salmon net cage farm** in Norway, including a physical structure with a handling capacity of 1 million juvenile fish (biomass weight of 4,738 tonnes after a 16 month growth phase) corresponds to an

approximate **€ 2 million** investment (including net cages, mooring, feed barge, storage, monitoring and feeding systems). An **Atlantic Salmon RAS** in Denmark with state of the art technology for 1,000 tonnes (with potential to expand production) is equivalent to a **€ 6.78 million** investment.

Also with regard to operating costs, which generally often exceed capital costs in the fish aquaculture sector, RAS systems are more expensive to run than net cage farms, because closed systems have higher energy costs to cover water circulation, water treatment and heating or cooling elements.

Fish feed often represents over 50 % of the fish farmer's production costs, even though fish have favourable feed conversion ratios compared to other domesticized animals. These costs are continuing to rise due to limited natural resources and rising commodity prices for fishmeal and fish oil. In general, production costs can be lowered through better use of feed, efficient feeding systems and vaccination of juvenile fish in open systems.

Most fish species do not reach market size in one season, meaning that aquaculture businesses must be able to endure a time period of no or low income until full production capacity is reached. If

**Table 3:** Capital and operating costs of open water net cage and land based RAS.

	Open Water Net Cage Aquaculture	Land Based Recirculating Aquaculture System
Capital investments	Net cages, mooring, harvesting equipment and feed barge, storing, grading and sorting equipment, protection against theft, feeding equipment, monitoring system licenses	Land, building, indoor drain, plumbing, effluent system, heating/cooling system, pumps, grow-out tank, reservoir tank, particle filter, biofilter, protein skimmer, oxygen incorporation, piping, feed storage, feeding system, harvesting equipment, water quality control equipment, monitoring and alarm system, backup generator, emergency oxygen system, licenses
Operating costs	Fingerlings, feed, mortality removal, disease treatment, net repair / replacement, predator control, harvesting, water quality control, maintenance, labour, management, operating fees	Fingerlings, feed, mortality removal, disease treatment, harvesting, water quality control, maintenance, water costs, sewage removal, oxygen price, electricity, labour, management, operating fees

production can be carried out as planned, four years must typically be allowed to reach full production capacity.

To reduce production costs and increase profitability, modern RAS businesses are advised to achieve a relatively high output with a minimum annual production capacity of at least 500–1,000 tonnes.<sup>24</sup> Furthermore, high operating costs have to be compensated by the production of high value fish species.

While RAS offer a more environmentally attractive solution to sustainable fish aquaculture compared to traditional open net cage systems, they are much more expensive to run. Adding IMTA solutions to existing net cages potentially offers a more cost-effective, environmentally sustainable solution as for almost the same costs, more products (e.g. mussels and algae) can be produced and sold. •

ADDITIONAL  
POINT

### THE “ECONOMICS” OF RESTOCKING

Generally the economics between aquaculture farms specialized on fish for human consumption or farms dedicated to restocking purposes differ not so much on the cost site but in the way prices are established for their products. Whereas the former have to calculate with normal consumer market prices, the latter depend on related government programmes, which pay for the environmental service provided by releasing hatchlings / juvenile fish to open waters.

As most of the costs depend on the location and the cultured species, naturally individual prices vary between the different countries within the Baltic Sea Region and no overall statement can be made to quantify the individual cost of fish production for restocking purposes. •

**Table 4:** Production costs by category for juvenile salmon producers in Norway (2008).<sup>27</sup>

	Cost per juvenile (€)	Cost share (%)
Roe and fry	0.12	14
Feed	0.11	13
Insurance	0.01	1
Vaccination	0.15	18
Wages	0.16	19
Depreciation	0.06	7
Other operating costs	0.21	25
Net financial costs	0.03	3
Total costs	0.85	100

## Employment

The EU aquaculture sector (both marine and freshwater) is estimated to generate approximately 65,000 direct full-time jobs<sup>28</sup> through mostly small and medium-sized aquaculture enterprises. In the Baltic Sea Region, the marine aquaculture subsector accounts for roughly 300 marine aquaculture enterprises (mainly small and medium-sized) with a total of 3,500 positions in part-time, full-time or seasonal jobs.

Modern aquaculture businesses in Europe often have highly automated operating processes, reducing the amount of employees directly involved in the production cycle while enhancing efficiency. Modern marine net cage farms often operate with 3–4 full time workers at each site including one manager. In closed systems the fish production per worker ratio can be even higher involving only one worker and one manager per facility. The indirect job creation in the fish processing and distribution sector is, however, likely to be considerably higher.

Marine aquaculture also plays an important role in wealth creation and contributes to regional development in otherwise economically deprived rural areas, where only a few alternative economic activities have been able to provide stable, long-term jobs.

## Political Strategies

### EU Strategies and Research Funding for Sustainable Aquaculture

The development of a more competitive and environmentally-friendly aquaculture industry is a major focus of European funding, both through the European Fisheries Fund (EFF) and EU research programs. In 2009, the Commission proposed a strategy<sup>29</sup> to give new impetus to the sustainable development of European aquaculture. The strategy focuses on three key elements: 1) promoting competitiveness of EU aquaculture production, 2) establishing conditions for sustainable growth of

aquaculture, and 3) improving the sector's image and governance. The EU aquaculture sector aims at being at the forefront of sustainable development, supported by advanced research and innovative technology.

The European Union itself is also a key contributor to research and technological development in aquaculture. € 98 million were allocated to research projects for aquaculture under the 6th Research Framework Program. In the 7th Research Framework Program, € 124 million are contributing to fund projects which are either directly or indirectly related to aquaculture, of which about one third (€ 27.7 million) concern environmental issues. Focus is placed on the development of sustainable and ecofriendly aquaculture.

With the beginning of 2014, the new financing period of the EU will start with the establishment of new European Maritime and Fisheries Fund (EMFF). The Fund shall help to deliver the ambitious objectives of the reform of the Common Fisheries Policy and will help fishermen in the transition towards sustainable fishing, as well as coastal communities in the diversification of their economies. "Smart, green aquaculture" will become one thematic topic ("pillar") with the EMFF striving to boost this industry in a sustainable manner, rewarding innovation and promoting also new strands of aquaculture, such as non-food aquaculture.

### Baltic Sea Region Strategies

Also Baltic Sea specific transnational and national strategies stress the necessity for a sustainable development of the aquaculture sector in the region and recognise its potential to play a key role in providing high quality and healthy seafood to consumers. To promote the sector, adequate framework conditions should be created and administrative burdens reduced. A main focus lies on further research and implementation of environmental friendly technology and compliance with best environmental practices. Table 5 gives an overview of the declarations, strategies and projects in place in

**Table 5:** Overview of declarations, strategies and projects in place in the Baltic Sea Region that seek to promote aquaculture at a national or regional level.

Baltic Sea-wide Declarations, Strategies and Projects
<ul style="list-style-type: none"> <li>• EU Baltic Sea Region Strategy: Improvement of management of Baltic Sea resources; introduction of best available technologies and practices in the field of advanced technologies of mariculture</li> <li>• Helsinki Declaration on Competitive and Sustainable Aquaculture in the Baltic Region, Aquaculture Forum, Helsinki, Oct. 6th 2011</li> <li>• HELCOM Recommendation 25/4 on limiting the pollution from fish farms to the Baltic Sea by using Best Available Techniques (BAT) and Best Environmental Practice (BEP). Both RAS and IMTA systems comply with the requirements of BAT and BEP.</li> <li>• Baltic Sea Region Programme Flagship project AQUABEST – Innovative practices and technologies for developing sustainable aquaculture in the Baltic Sea Region</li> <li>• Baltic Sea Region Programme AQUAFIMA project – Integrating aquaculture and fisheries management towards a sustainable regional development in the Baltic Sea Region</li> </ul>
National and Regional Declarations and Strategies
<ul style="list-style-type: none"> <li>• <b>Sweden</b> – <i>Det växande vattenbrukslandet</i>: Aquaculture nation in the making, a national action plan</li> <li>• <b>Denmark</b> – <i>Anbefalinger til en bæredygtig udvikling af dansk akvakultur</i>: Recommendations to the sustainable development of Danish aquaculture, main Report by the Government's aquaculture committee of 2009</li> <li>• <b>Poland</b> – Programu Operacyjnego “Zrównoważony rozwój sektora rybołówstwa i nadbrzeżnych obszarów rybackich na lata 2007-2013”: Balanced development of the Fishery sector and coastal fishery regions for 2007 – 2013</li> <li>• <b>Latvia</b> – Sustainable Development Strategy of Latvia until 2030</li> </ul>

the Baltic Sea Region that seek to promote aquaculture at a national or regional level.

## Legal Aspects

Legal considerations within the aquaculture sector differ substantially from those of normal fisheries, since, in contrast to fishermen who do not take property until hauling, in aquaculture the aquatic organisms are the property of the operator at all times.

It is difficult to give an overview of legal aspects involved in the aquaculture industry, as these are highly dependent on where the facility is planned, which system is planned and which aquatic organisms shall be engaged. Also of importance is whether

a facility has a direct output of effluent waters into natural water bodies or if they are directed into sewage systems.

Different rules exist for farms on land-based sites or for farms situated directly at sea, i.e. in coastal waters and the Exclusive Economic Zone (EEZ). Generally, however, coastal states also have the exclusive right to authorize and regulate the construction and operation of marine aquaculture installations within the Exclusive Economic Zone (EEZ), as this is regulated by the legislation of the coastal states adopted by the *United Nations Convention on the Law of the Sea*.

Essential in any case is the assessment / legitimacy of the planned operation against the background

of site-specific environmental impacts and stakeholder objections both regulated at national and regional levels as well as relevant environmental EU-wide directives.

The extent and form of legal requirements for an aquaculture establishment differs substantially between the various Baltic countries and regions. Nevertheless the following sample list provides an impression of some of the legal aspects and regulations that must be taken into account:

- The Water Framework Directive (2000/60/EC) also pertains to aquaculture since it addresses the area extending up to one sea mile seawards from the coastline. Article 1 requires the enhancement of the status of aquatic ecosystems and Article 4 aims to prevent deterioration of all bodies of surface water.
- The area further seawards is then covered by the Marine Strategy Framework Directive (2008/56/EC), which also lists mariculture in Annex III Table 2 “Pressure and impacts” under “Nutrient and organic matter enrichment”, for which contracting parties are obliged to achieve good environmental status.
- Art. 8 lit. h of the Convention on Biological Diversity as well as EU Council Regulation (EC) No 708/2007 require the control of any alien species with might threaten the ecosystem and apply to aquaculture operators.
- Also an assessment according to Art. 6 para. 3 of the Habitats Directive (92/43/EEC) may be needed. According to this provision, any plan or project likely to have a significant effect on a protected site under Natura 2000 shall be subject to appropriate assessment.
- In Germany the Federal Act on Environmental Impact Assessment (EIA) requires in any case that intensive fish farming plans conduct an EIA.
- Overall the dumping of substances represents a fact of use (“Benutzungstatbestand”) according to the Water Management Act (§9 para. 1 no. 4) in Germany, which requires a special permission (§ 8 para. 1).

**Table 6:** Responsible authorities for mariculture establishments in the Baltic Sea Region countries.

Country	Responsible authority for licenses, permits and control of mariculture establishments
Germany	Federal state water authorities (mariculture in coastal waters) Federal Maritime and Hydrography Agency (mariculture in the EEZ)
Sweden	Board of Fisheries and the Board of Agriculture Local administration and licenses issued by County Administrative Boards (occasionally in combination with the Water Rights Court)
Finland	Regional Environmental Permit Authorities
Denmark	Directorate of Fisheries (Application approval by the Danish Coastal Authority, Ministry of the Environment, Danish Veterinary and Food Administration, Danish Maritime Safety Administration, Danish Institute for Fisheries Research, Danish Fishermen’s Association)
Estonia	The Fishing Industry Department, Ministry of Agriculture (freshwater aquaculture)
Latvia	National Board of Fisheries of the Ministry of Agriculture (freshwater aquaculture)
Lithuania	Federal administrations of the Minister of Agriculture and the Minister of the Environment regulate the establishment of new aquaculture activities. Licenses are not necessary (freshwater aquaculture).
Poland	Ministry of Agriculture and Rural Development, Department of Fisheries and local authorities (freshwater aquaculture)

## LABELLING AND CERTIFICATION

Labelling and certification are important parameters in a product strategy, especially when entering international trade. In 2002 the EU introduced new labelling requirements for fishery products specifying that all products shall carry labels that state among others the production method (capture or farmed), catch area of wild species (FAO fishing area) and the country of production in the case of farmed fish products.<sup>30</sup>

The usefulness of eco-labelling in creating a market-based incentive for environment-friendly production was recognized about two decades ago when the first eco-labelled products were put on sale in Germany in the late 1970s. Since then, and especially during the 1990s, eco-labelling schemes have been developed in most industrialized countries for a wide range of products and sectors

In order to promote sustainable aquaculture practices and maintain market shares in eco-sensitive export markets, the aquaculture industry is developing eco-labelling schemes for those products, which are deemed to have fewer impacts on the environment than functionally or competitively similar products. The so-called “Aquaculture Stewardship Council” shall act as the correspondent label to the currently widely spread “Marine Stewardship Council / MSC” for sustainable fishery.

Eco-labelling criteria are for instance the amount of fishmeal as well as fish density in ponds. Whereas these efforts apply to net cage systems, EU regulation No 710/2009 article 25G on organic aquaculture animal and seaweed production, currently still prohibits closed recirculation aquaculture animal production facilities (i.e RAS) from such eco-labelling schemes in view of non-sufficient space and animal wellbeing.<sup>31</sup>

## SWOT Analysis

### GENERAL SWOT

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> <li>• Provision of high quality and healthy seafood for human consumption not affecting natural fish stock populations</li> <li>• Growth in development of new systems with decreased impact on the environment</li> <li>• Contribution to the well-being of coastal regions</li> <li>• Facilitation of structural transformation from fisheries to aquaculture without losing jobs</li> <li>• Creation and strengthening of a domestic market and reduction of import reliance</li> <li>• Contribution to protection of natural fish stocks and reduction of environmental impacts</li> <li>• Environmentally friendly activity in terms of reduction of transport needs and CO<sub>2</sub> emissions</li> <li>• Availability of qualified employees (well developed university and training courses)</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of good practices (few farms are running on a commercial basis to provide examples)</li> <li>• Hardly any tradition of marine aquaculture in the Baltic Sea Region</li> <li>• No well-functioning processing chain for aquaculture products</li> <li>• Fish feed still largely dependent on fish meal from capture fisheries</li> <li>• Long time to reach full production capacity (ca 4 years) due to fish growth rates</li> </ul>
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> <li>• Growing demand for food</li> <li>• Growing demand for high quality seafood in Baltic Sea Region countries</li> <li>• Growing demand for Baltic Sea Region brand products</li> <li>• World fish capture production expected to stay stagnant</li> <li>• Declining fish stocks due to overfishing</li> <li>• Global development of the aquaculture sector, especially in the high quality/price sector</li> <li>• EU support in form of Integrated Maritime Policy and structural funds</li> <li>• Combination with other marine uses may improve financial viability</li> <li>• Growing development of high-technology</li> <li>• Global drive towards sustainable development</li> </ul>	<ul style="list-style-type: none"> <li>• Low public acceptance for locally produced aquaculture products (too little public awareness)</li> <li>• No enough political support</li> <li>• No investment and financial support due to the actual economic and financial crisis</li> <li>• Competition from other countries producing cheaper products and having longer experience</li> <li>• Continuously rising prices of fish meal</li> <li>• Worsening Baltic hydro-meteorological conditions due to climate change</li> <li>• Potentially increasing nature protection requirements</li> <li>• Low quality standards and regulations for fish cultures as well as water treatment in many non-EU countries</li> </ul>



RECIRCULATING  
AQUACULTURE  
SYSTEMS

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> <li>• Environmentally friendly and sustainable food production</li> <li>• Already existing technology, know-how and a variety of companies for plant construction and operation of closed RAS</li> <li>• Easy to combine with other uses such as biogas plants</li> <li>• Low land and water requirements</li> <li>• All-year constant seafood production possible</li> <li>• High safety standards applicable</li> <li>• Good substitute to “traditional” mariculture where the latter one is impossible due to lack of suitable places</li> </ul>	<ul style="list-style-type: none"> <li>• Few new RAS start-ups</li> <li>• Highly experienced employees necessary to run RAS</li> <li>• High running costs in terms of electricity and water use as well as high investment costs for plant construction</li> <li>• Long process for new fish species to be reared in RAS to achieve market appeal</li> <li>• Limited possibility of water use and discharge due to strict regulations</li> <li>• No eco-certification</li> </ul>
OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> <li>• Expanding technological progress</li> <li>• Combination with other uses such as biogas plants as heating source and use of waste water for greenhouses improves financial viability and environmental standards</li> <li>• Support from the side of environmentalists and politicians</li> </ul>	<ul style="list-style-type: none"> <li>• No local and public support for building new RAS plants</li> <li>• capital investment relatively high because of the technical components</li> <li>• Well trained employees are obligatory</li> </ul>

OPEN WATER  
NET CAGE  
AQUACULTURE  
WITH IMTA

STRENGTHS	WEAKNESSES
<ul style="list-style-type: none"> <li>• Highly developed technology and know-how for open net cages</li> <li>• With IMTAs even more cost-efficiencies due to more products which can be sold</li> <li>• Automatized feeding, monitoring and harvesting processes potentially reducing production costs</li> <li>• Ease of combination with other uses (e.g. offshore wind farms), increasing profitability and optimizing sea area use</li> <li>• Potentially eco-certified.</li> </ul>	<ul style="list-style-type: none"> <li>• Only limited areas with suitable coastal morphology and water parameters</li> <li>• Also with IMTA still possible negative impacts on the ecosystem due to pollution and especially escapes and diseases which may affect natural fish populations</li> <li>• Fish growth limited to warm seasons</li> <li>• Sensitivity to ice drifts</li> <li>• Very limited practical knowledge on IMTAs and lack of related research / pilot sites</li> </ul>





OPPORTUNITIES	THREATS
<ul style="list-style-type: none"> <li>• Technical progress allowing development of existing net cages farms towards a sustainable IMTA approach</li> <li>• Further development of offshore wind energy in the Baltic Sea Region offering increased opportunities for combination of space use.</li> </ul>	<ul style="list-style-type: none"> <li>• No licences for new marine aquaculture start-ups in general</li> <li>• Long term effects / impacts of integrated systems unknown</li> <li>• Opposing stakeholder interests</li> </ul>

## Knowledge Gaps

There is little experience with RAS and IMTA technology in the Baltic Sea Region and the long term impact of deploying these systems is unknown. Further research would be beneficial in a number of areas.

These include:

- Improving water treatment techniques
- Developing sustainable feed supply chain
- Improving feeds so that higher nutrient fractions are retained by the fish
- Applying carbon neutral alternative energy sources to meet high energy demands of running RAS
- Selection of species appropriate to habitats, environmental conditions and available technology
- Economic feasibility studies of IMTAS
- Monitoring the efficiency of nutrient uptake by IMTA systems
- Combining marine fish aquaculture with other marine uses to improve its financial viability
- Potential sites for open and/or closed systems in the Baltic Sea Region

## Conclusions

The main opportunities of a growing, well organized and ecologically sound marine aquaculture sector in the Baltic Sea Region lie mainly in the growing desire for regional and environmentally friendly marine food products as a substitute for fish / fish aquaculture imports from overseas. The

Baltic Sea Region countries have a well-functioning technology sector on which aquaculture companies can rely on to plan, construct and operate aquaculture systems which are technologically advanced and thus more environmentally friendly.

However, the main weakness of the current marine aquaculture sector in the Baltic Sea Region, compared to that of other regions, is that there are only few successfully operating marine aquaculture companies, especially ones which are using modern environmentally friendly technology, to take as example for future start-ups.

The implementation of innovative aquaculture systems such as RAS, IMTA and other combined uses must therefore be carefully examined for each country and region individually. Countries which already have marine aquaculture activity, mainly in form of nearshore net cage farms, might choose to strengthen their industry by using the advantages of existing infrastructure and introducing innovative technology such as IMTA to already existing farms. In addition, new emerging systems such as RAS could be established were suitable coastal sites are already in use. Countries where marine aquaculture is not yet establish due to a lack of suitable nearshore sites as well as other reasons, might seek to introduce aquaculture systems that are land-based.

Additional importance lies on the necessity to create public awareness and ultimately public acceptance for sea food produced in marine aquaculture in the Baltic Sea Region. When planning the development of the mariculture sector and

eventually building new facilities all stakeholder interests must also be taken into consideration. The sectors with high conflict potential are tourism, fisheries, shipping and nature conservation. Detailed communication and establishing agreements between different stakeholder groups during the planning process may avoid problems in the long run.

Generally the findings of the SWOT analysis on the further development of the marine aquaculture sector in the Baltic Sea Region – if conducted in a sustainable way – can be summarised as follows:

- 1 A sustainable development of the marine aquaculture sector in the Baltic Sea Region could have several positive economic (local food fish production), socioeconomic (job creation) and environmental (fish stock enhancement) advantages.
- 2 A suitable strategy for the sustainable development of the Baltic Sea Region marine aquaculture sector must be developed in coherence with the individual environmental conditions and legal characteristics of each country and region.
- 3 The use of environmentally friendly seawater Recirculating Aquaculture Systems could contribute to the sustainable development of the Baltic Sea Region marine aquaculture sector.
- 4 Already established marine net cage farms could extend their systems by using an integrative approach (IMTA), thereby reducing environmental impacts.
- 5 Offshore wind farms provide a possible opportunity for a combined use with marine aquaculture farms. Other viable combinations are also desirable.

## Recommendations

Special strategies must be developed to pursue the opportunities identified, avert threats and eliminate weaknesses by using the strengths that would arise from a well-developed ecologically sound marine aquaculture sector:

- A positive example of a financially viable and sustainable aquaculture company in the Baltic Sea Region should be created as reference for future start-ups, facilitating financial help and attracting investment
- Production of a “Baltic Sea Region brand” for high quality and high value marine aquaculture products should be supported to avoid competition with established aquaculture sectors around the world
- Public awareness should be strengthened for locally produced endemic species instead of exotic species that require long distance transport
- The domestic market should be strengthened, resulting in less reliance on fish imports, food security and a decrease of transport emissions
- A local market for products should be created and regional producer groups should be established to boost the marketing of new species, simplify sales structures and reduce costs
- Promote new fish species for consumer markets.
- Proper education should be available to avoid a shortage of trained personnel
- Research in the areas of water treatment, feed supply and efficiency, environmental impacts, should be supported.