J Coast Conserv (2018) 22:115–130
DOI 10.1007/s11852-017-0509-5

Potential, constrains and solutions for marine aquaculture in Kiel Bay & Fjord

Kai Ahrendt[1] · **Horst Sterr**[2] · **Peter Krost**[3] · **Wilhelm Windhorst**[4] · **Michael Schultz**[5]

Received: 23 November 2016 / Revised: 21 March 2017 / Accepted: 23 March 2017 / Published online: 5 April 2017

Abstract Marine aquaculture is facing a variety of competing uses in densely populated coastal areas such as the coast of Kiel Bay. Thus, a major barrier for extending the marine aquaculture business could be the lack of suitable space for "offshore farming". Moreover, in public opinion the aquaculture sector is often associated with a negative image derived from environmental concerns. It might therefore be expected that planning aquaculture installations in Kiel Bay & Fjord would face resistance both from other offshore stakeholders and the public. This study therefore addressed the question whether arguments and criteria can be found that may contribute to a greater support and positive image of local aquaculture enterprise, thus fostering political support for this sector as well. Indeed, a widespread regional survey showed less public reservation towards aqua-cultural business in Kiel Fjord than initially expected. However, expanding the entrepreneurship in the regional aqua-cultural sector will only be successful if the installations can avoid a significant deterioration of the water quality in Kiel Fjord, e.g. through excessive emissions of nutrients from net cages. An important step forward toward this goal is the concept of IMTA = Integrated Multi-Trophic Aquaculture. The IMTA concept spatially integrates nutrient emitting installations such as fish net cages with installations of nutrient extracting organisms, e.g. mussels and algae. Based on spatial analyses of marine environmental parameters and through modelling of nutrient mass balances (emitted versus extracted nutrient quantities) possible locations, types and sizes of aquaculture installations can be determined.

Keywords Aquaculuture · Baltic Sea · IMTA · Mariculture

Introduction

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 (Schultz-Zehden and Matczak 2012). Aquaculture not only provides fish for human consumption but also serves other marine production needs (Fig. 1).

Aquaculture raises a number of challenges with regards to the sustainability of production and during the last decade, there has been much debate about what sustainable fish aquaculture actually is and how it could be realized. The primary issues relate to:

- Environmental concerns deal, among others, with the quantity of land, water and energy used; water quality, release of effluents / nutrients and of alien species. Because of widespread consideration of such environmental concerns in the media, marine fish cultivation sometimes has image problems in public discussions.

✉ Kai Ahrendt
Ahrendt@iczm.de

[1] Company for Environment and Coast, Steinstraße 25, 24118 Kiel, Germany

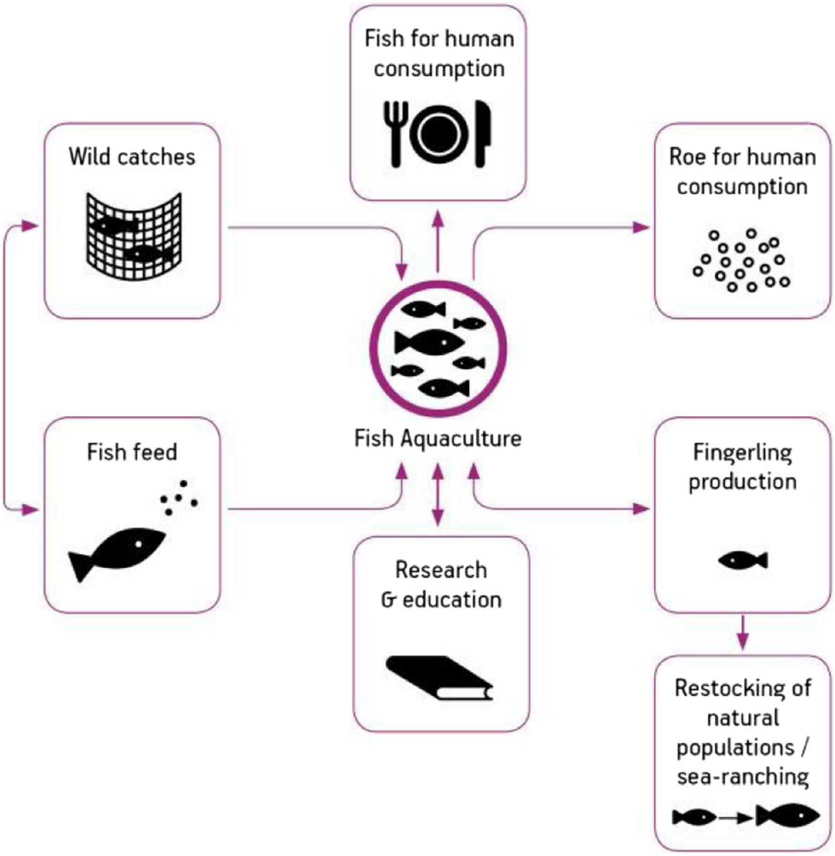
[2] Department of Geography, University of Kiel, Ludewig Meyn Straße 14, 24118 Kiel, Germany

[3] Coastal Research and Management GmbH, Tiessenskai 12, 24059 Kiel, Germany

[4] Institute of Natural Resource Conservation, University of Kiel, Olshausenstraße 75, 24118 Kiel, Germany

[5] Research Center Jülich/PTJ, Zimmerstraße 26, 10969 Berlin, Germany

Fig. 1 Applications of fish aquaculture and its interaction with various other practices and resources (source: Schultz-Zehden and Matczak 2012)



- Economic issues focused on profitability, market demand and improved feeding efficiency.
- Socio-political interests centred on employment, local conflicts with fishermen, regional resource use and marine governance.

In Germany the aquaculture sector is constantly gaining importance. In 2014 a National Strategy Plan for Aquaculture (NASTAQ) documented both the status-quo of the sector and the long-term development goals. Subsequently, the State of Schleswig-Holstein adopted and specified this development plan for the coastal areas of the North Sea to the west and the Baltic Sea to the east, also outlining specific measures to enhance and improve options for regional sustainable aquaculture (Melur 2014). The coastal waters in this region are very well suited for marine aquaculture, but up to now only mussel farming along the North Sea coast has gained economic importance. According to the State Plan aquaculture production could also be increased in the waters of Kiel Bay & Fjord but need to take nearby uses of the coastal area as well as strict environmental regulations (e.g. European Water Framework Directive) into consideration. In Germany environmental concerns often play a major role in public planning and political decision-making and these concerns might also affect the development of the aquaculture sector. Thus, the key questions of this study are

- What is the public opinion of coastal residents about promoting marine aquaculture?
- What technical options are available to keep environmental impacts to a minimum?
- Where are the suitable locations for marine aquaculture installations?
- What decisions and actions need to be taken at the political level to reach long-term goals for marine biotechnology?

Public views on marine aquaculture

Based on previous international studies and regional experience it seems obvious that public attitudes and stakeholder interactions may play an important role in determining the social acceptability of aquaculture. In the past environmental and social aspects raised public concerns about the aquaculture industry. In addition, environmental impacts and their negative feedbacks often influence governance and political will regarding mariculture. Hence, one of the key factors for the future expansion of mariculture in Schleswig- Holstein seems to be the awareness of the importance and benefits of this sector. Within the framework of a cooperation project between Germany and Israel (Schultz 2012), a socio-political study was carried out to understand local factors that influence attitude formation and interrelationships towards aquaculture. By carrying out a widespread survey among citizens from Kiel and neighbouring communities, the study obtained significant insights for policy, business, environmental NGOs and other stakeholders. One of the key questions of the study was: What is the attitude of the major stakeholder groups and policy makers towards marine aquaculture? Considering the fact that knowledge about marine aquaculture is still sparse in Germany the survey provided a table which listed 6 possible advantages and 6 possible disadvantages of marine aquaculture and asked respondents to choose the four most important points out of the 12 (Table 1). The mariculture issues were chosen in consultation with experts including representatives of environmental organizations and of the regional economy.

Moreover, the survey included a section on respondents' willingness to pay a premium for farmed fish raised in an environmentally friendly manner as well as perspectives for marine aquaculture under ecological supervision in the region.

The results from presenting these positive and negative choice options showed three estimated advantages of aquaculture versus only one disadvantage, in the following ranking (Schultz 2012):

- No overfishing of natural stocks and no unwanted by-catch (= advantage)
- No mechanical destruction of natural habitats by fishing gears, as in traditional fishery (=advantage)
- Fish and products from aquaculture facilities are not as healthy wild-caught fish and seafood (=disadvantage)
- Reliable food source for the growing global population (= advantage)

The results reveal that information delivered by the media strongly influences attitudes of the wider public. The German public opinion is primarily guided by concerns about depletion of wild fish stocks due to overfishing fishery, and only to a lesser extent by concerns about potential marine pollution due to emissions from fish farms. Overall aquaculture was perceived as a potential alternative to fisheries.

An additional and unexpected finding of the study was a positive relationship between tourism and mariculture, an aspect that might be of interest for future spatial planning.

Environmental constraints: what solutions are available?

Generally speaking marine aquaculture includes, in addition to fed finfish, extractive installations such as mussel and algae cultivations, which remove nutrients from the water body as well as nutrient emitting installations, e.g. fish farms. These fish farms are often very valuable from an economic point of view but might be harmful to marine environments due to additional nutrient input. Fish cages normally consists of a floating frame, a net to enclose and a mooring system. It can be placed in 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 algal or jellyfish blooms or low oxygen levels. Thus only a limited number of suitable sites exist throughout the Baltic Sea Region, usually within the semi-enclosed fjords and bays. The most important disadvantage, however, is the environmental concern related to waste effluents as well as fish escapes and transfer of diseases from farmed to natural fish populations. As the near-shore coastal waters have been suffering from high eutrophication levels for many years, additional nutrient influx from expanding fish cultivation needs to be avoided. Water quality is nowadays fairly strictly governed by the European Water Framework Directive which forbids significant deterioration of marine waters in the EU. The political strategy at state level therefore supports new opportunities such as combination of traditional fish cages with integrated systems, which may decrease the environmental impacts, the so-called Integrated Multi-Trophic Aquaculture = IMTA.

Table 1 Public opinion on advantages and disadvantages of marine aquaculture (Schultz 2012)

Advantages – Examples	Disadvantages – Examples
No overfishing of natural stocks and no unwanted by-catch	Additional degradation and contamination of water and sea bottom
No mechanical destruction of natural habitats by fishing gears (as in traditional fishery)	Loss of employment (e.g. in the regional fisheries sector)
Production of healthy food	Fish farms disturb the natural beauty of the coasts and thus harm the tourism sector
Creation of new jobs /employment	Fish and products from aquaculture facilities are not as healthy as from free-living organisms
Reliable food source for the growing global population	Development of fish meal and fish oil
Economic boost in coastal areas which are only weakly developed	There are ethical concerns about intensive livestock farming

One example of IMTA is the combination of fish culture with macro-algae and invertebrate culture but micro-algae cultivation is also possible (see further below).

Invertebrates and seaweeds filter and absorb the nutrients from the fish operations. Thus, not only the farmed fish will 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. macro-algae) and particulate nutrients by filter feeders (e.g. mussels), and through harvesting, removing the nutrients from the location. Furthermore, using the harvested mussel and macro-algae biomass for fish feed is an indirect reduction of the environmental pressure on wild stocks exploited for fish feed.

Because both macro-algae and mussels have been successfully cultivated in Kiel Bay & Fjord for some years this presents promising perspectives for an IMTA strategy there. Whereas the IMTA concept is strongly supported by the aquaculture strategy plan of the State of Schleswig-Holstein (Melur 2014) it requires careful calculation, modelling and monitoring of the nutrient mass budget in order to be sustainable.

Nutrient mass balance budgets may indicate the input, flux, uptake and removal of nutrients but do not accurately quantify their turnover in a specific area. Hydro-numerical modelling helps us calculate fluxes in time and space for specific natural conditions. A combination of mass budgets and hydro-numerical modelling will lead to a better understanding of how IMTA can be managed optimally as described in the following chapters.

Nutrient budget and mass balance around a fish farm

Whereas the government of the state of Schleswig-Holstein supports the installation of aquaculture facilities in coastal waters this activity cannot involve the elevation of nutrient levels beyond background concentrations (Melur 2014). However, raising fish in net cages at sea inevitably involves the emission of nutrients into the surrounding system, both in dissolved and particulate form. Thus, and in order to get the required permits, an equivalent amount of nutrients needs to be removed from the natural system.

The crucial nutrients insofar as impact on water quality are nitrogen (N) and phosphorous (P). Inorganic dissolved nitrogen (DIN) is released from aquaculture as fish extraction and as a result of the bacterial breakdown of particulate organic material. Particulate organic nitrogen (PON) is found in fish faeces, scales and in uneaten feed (as proteins), while Phosphate is emitted predominantly as particulate organic phosphorous (POP) in fish faeces where it is subject to subsequent release as dissolved inorganic phosphorous (DIP) after bacterial breakdown. DIN and DIP both are essential nutrients for plant growth and contribute to the eutrophication of coastal waters, the major environmental concern in the Baltic Sea.

The debate on fish farming in Schleswig-Holstein waters was fuelled by the intention of a foreign investor to start a large aquaculture operation (5000 tons) in Kiel Bay 7 years ago. The original plan envisaged 4 units of net cages, each with a production capacity of 1250 t. Although this initiative was dissolved, aquaculture is still considered a potential future industry for Schleswig-Holstein, provided that the problem of nutrient emissions can be solved. This paper explores an option that would enable the development of a fish farm with minimal nutrient release to the surrounding waters.

In the following we focus on one unit of the proposed farm with a production of 1250 t fish per year. For our calculations we assume that the farm encompasses 12 net cages, each with a diameter of 26 m and a distance between cages of 25 m. The assumed dimension of such a farm is shown in Fig. 3. Anchor ropes stretch approx. 100 m in all directions. The width of the maintenance corridor is 100 m. Summing up the dimension of the farm is 328 m resp. 404 m (Fig. 2). One farm with 1250 t fish production per year thus covers an area of 132,512m^2.

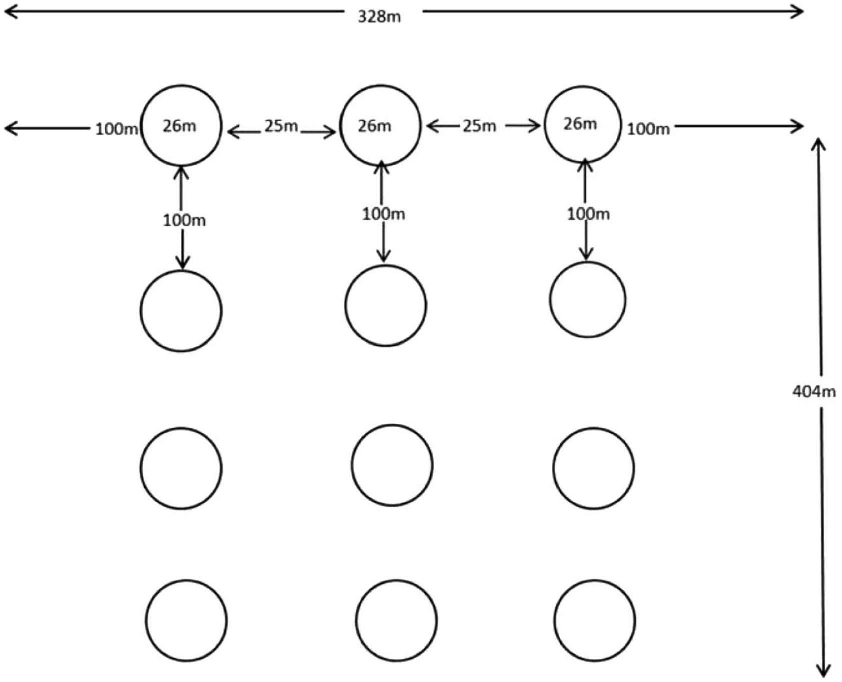
Due to the climatic and hydrographic conditions in Kiel bay, the most promising species to be cultivated is rainbow trout. Juvenile fish weighing 0.3 kg to ca. 0.5 kg are stocked in the cages in spring, and - according to experience from local farmers - reach a weight of approx. 3.5 kg (personal communication SNAPTUN Ltd.) at harvest time in autumn. This equals a gain in biomass of approx. 1,070,000 kg for the whole farm. The feed conversion ratio (FCR) is assumed to be 1.1, according to present cultivation standards. Following this ca. 1,177,000 kg of feed is needed in one year (Fig. 3).

Reference feed for our calculations is a commercial trout feed by BioMar (BioMar EFICIO Enviro 926). The composition data is provided by the manufacturer.

38% of the feed consists of protein, which equals 447,260 kg for the yearly feed input. Proteins have an average N content of 16%, from which we calculate an annual N-input of 71,562 kg. The content of P in feed is 0.8%, corresponding to 9416 kg from the annual feed input. Feed compositions of other manufacturers differ slightly. For a quantification of the metabolic conversion we follow the review by Olsen et al. (2008). While 38% of N and 31% of P will be incorporated into fish biomass (Fig. 4), the remaining nutrients are released into the sea.

42% of N input, or 30,056 kg per year are lost in dissolved form (DIN, predominantly ammonia) due to the excretion of the fish, another 20% (14,312 kg per year) are lost in particulate form in the faeces. 15% (or 2147 kg) of the N- content of

Fig. 2 Module with 1250 t fish production per year without multi-trophic unit



the latter is released as dissolved organic N (DON) in a very short time (5–15 min) after faeces are released and the remaining 12,165 kg will seettle to the sea floor. In summary, the total annual input of N is 44,368 kg, of which 12,165 kg are in particular and 32,203 kg in dissolved form. The further fate of the settled material depends on accumulation rates and the breakdown of organic matter as a result of benthic and microbial activity. Part of the settled material is permanently buried, while another part is subject to re-mineralisation and subsequent release into the water column as DIN. As the proportion and speed of remineralization is not yet reliably quantified, the re-mineralised fraction is not included in the calculation for nutrient compensation.

19% (1789 kg) of the P content of feed is excreted as phosphate (DIP), while 50% (or 4708 kg annually) of P is released as faeces. Leaching of P from these faeces accounts for release of an additional 15% (706 kg) of dissolved organic P (DOP), and the remaining 4002 kg will settle to the sea floor, where it will be permanently buried and/or re-mineralised as in the case of N.

In summary, and following the scheme in Fig. 3, cultivation of 1250 t rainbow trout releases ca. 44,368 kg N and ca.

Fig. 3 Scheme of matter flow in an aquaculture farm (after Olsen et al. 2008)

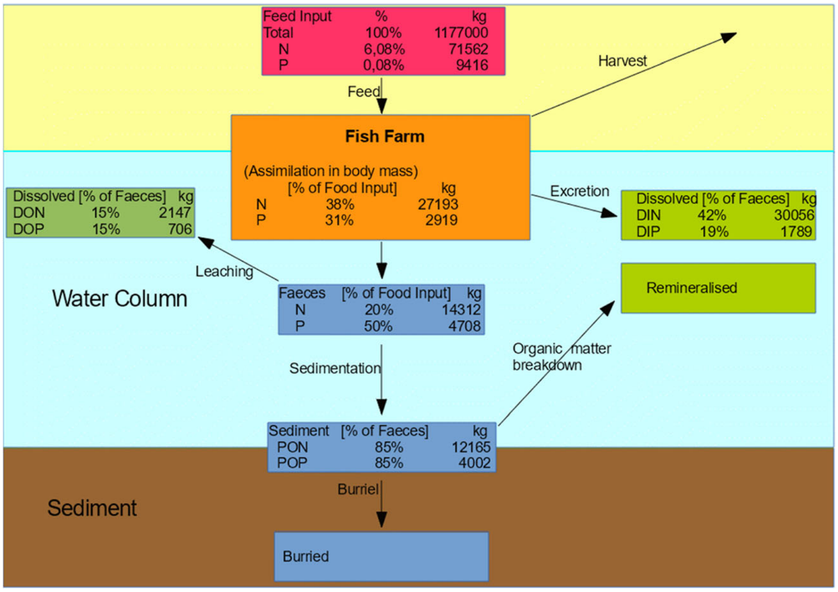


Fig. 4 Locations of investigation areas (source: Google Earth)

6497 kg P annually. According to Melur (2014) this operation can only be sustainable realized by a nutrient retention in the same magnitude. Research on optimization of feed has led to dramatically improved feed utilization efficiency (Skjermo et al. 2014). Improved farm management has minimized feed spill, which renders further improvement of this aspect effectively impossible. Only a few methods for nutrient retention have been applied in open water systems. For purpose of this specific case study (Kiel), we propose the combination of mechanical removal of faeces and extractive aquaculture (see below) as a scheme to enable sustainable aquaculture.

Mechanical capture of the faeces can theoretically prevent discharge of particulate waste at a rate of 12,165 kg N and 4002 kg P annually. The technological possibilities are discussed further below.

Another means of nutrient removal is the compensatory production and subsequent harvest of “extractive” aquaculture crops. In the case of complete mechanical removal of fish faeces, the remaining 32,203 kg dissolved N and 2495 kg dissolved P must be retained by organisms and can then be removed by harvest. This requires extractive organisms with high productivity (and therefore a high nutrient demand and uptake), and – optimally – with a (high) market value. Organisms with high productivity in the Western Baltic are microalgae, kelp and mussels.

Microalgae have a very high production potential but the technology is still very new and under development. Kelp production has been discussed and applied in Danish waters in recent years. The content of N in sugar kelp (*Saccharina latissima*) is ca. 0.52%, the P content 0.09% of wet weight.

Skjermo et al. (2014) report that 170 – 220 t (max. 300 t/ha) sugar kelp per ha could be harvested along the Norwegian coast. Experiences from a sugar kelp farm in Kiel Fjord, however, show, that productivity at this order of magnitude cannot be reached in Kiel Bay, as the hydro-physical conditions, predominantly the salinity, are different. We therefore see no realistic chance for a large scale production of sugar kelp in Kiel Bay that could be applied for nutrient compensation of fish farming.

On the other hand blue mussels (*Mytilus edulis*) are highly productive in the waters around Kiel. Blue mussels have an N content of ca. 1% of wet weight. According to Gren et al. (2009) a harvest of 50 t $ha^{-1}*y^{-1}$ is possible (100 t/ha in a production cycle of 2 years), and can thus extract ca. 500 kg N $ha^{-1}*y^{-1}$. For the removal of the total N released caused by the production of 1250 t fish y^{-1}, ca. 4437 t of mussels need to be harvested, which requires an area of 89 ha. To compensate for the fish farm discharge of 6497 kg of P, a total harvest of 9281 t of mussels and an area of 186 ha is needed. A mechanical pre-treatment step (e.g. by catching the settling faeces, or removing settled organic

Table 2 Required mussel production and area for nutrient compensation of a 1250 t fish farm

	N [kg]	P [kg]
Particulate input	12,165	4002
Dissolved input	32,203	2495
Total input	44,368	6497
Mussel composition	1%	0,07%
Mussel production [t ha^{-1} y^{-1}]	50	50
Required biomass for total compensation by mussels [t]	4437	9281
Required area for total compensation by mussels[ha]	89	186
Required biomass after mechanical pretreatment[t]	3220	3564
Required area after mechanical pretreatment [ha]	64	71

material from the seafloor) will reduce the need for such extensive mussel filtration - and thus the required area - significantly. Due to the relatively high content of P in faeces, only 3564 t of mussels have to be harvested when carrying out a pre-treatment, which can be produced on an area of 71 ha (see Table 2).

Hydro-numerical modelling

The hydro numerical modelling software MIKE21 (Danish Hydraulic Institute 2015) was used to model the nutrient flow and the faeces drift for two specific field sites in Kiel Bay. The software is composed of three modules. The basic one is the hydrodynamic (HD) module MIKE21HD. MIKE21HD calculates the current conditions as basis for the particle tracking (faeces) module MIKE21PT and the module MIKE21AD for the advection/dispersion of the nutrients. This is a two dimensional modelling process. Three dimensional modelling is not necessary in this location because stratification can be neglected, i.e. we assume the water column is fully mixed.

MIKE21HD for hydrodynamic conditions

The MIKE21 Flow Model, a modelling system for 2D free-surface flows, is applicable to the simulation of hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas and seas.

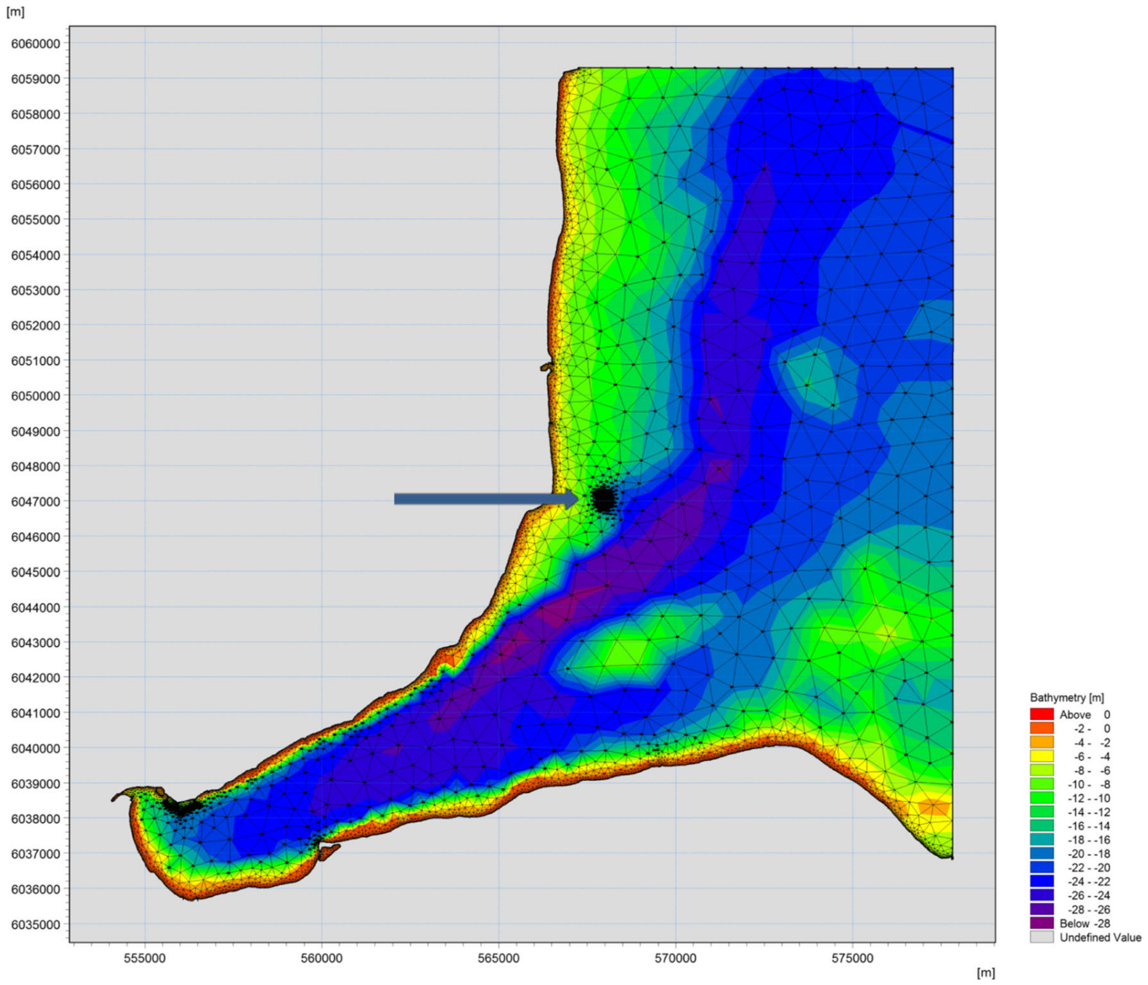


Fig. 5 Mesh and depth structure of the field Bookniseck aquaculture site (ca. 25 m diameter)

This module can be run in a grid or a flexible mesh version. The grid version has a constant distance between grid points and the mesh version has a flexible description of the bathymetry, resulting in reduced calculation time.

The underlying bathymetric data for setting up the bathymetry are the official data from the Federal Maritime and Hydrographic Agency of Germany (BSH). Three tidal gauges are available in the region and deliver water level oscillation at a 1 min interval. The modelling was carried out for a period of 1 week in time steps of 3–30 s. The Coriolis force was included. Wind conditions were set as constant with a speed of 10 m/s and a direction of 245°. Additional variables are bottom roughness, water temperature (10°), salinity (16 psu).

Additional variables may be included, but the major variables that effect the hydrodynamics are: sea level change, wind, water depth and Coriolis force.

MIKE21AD for dissolved matter

The advection/dispersion module simulates the spreading of dissolved substances subject to advection and dispersion processes. The location of the source of the nutrients is specified in the HD module. No chemical or biological processes are included. A cultivation period of 8 months (corresponding to 240 days = 5760 h = 345,600 min = 20,736,000 s) was assumed. MIKE computes calculation in one second steps and the discharge was converted to an emission rate of 1.5 g N and 0.12 g P per second by dividing the total discharge by the total time in seconds. The emission was as assumed to be constant for the calculation period. The boundary conditions were also set as constant with natural background values as well as the initial conditions.

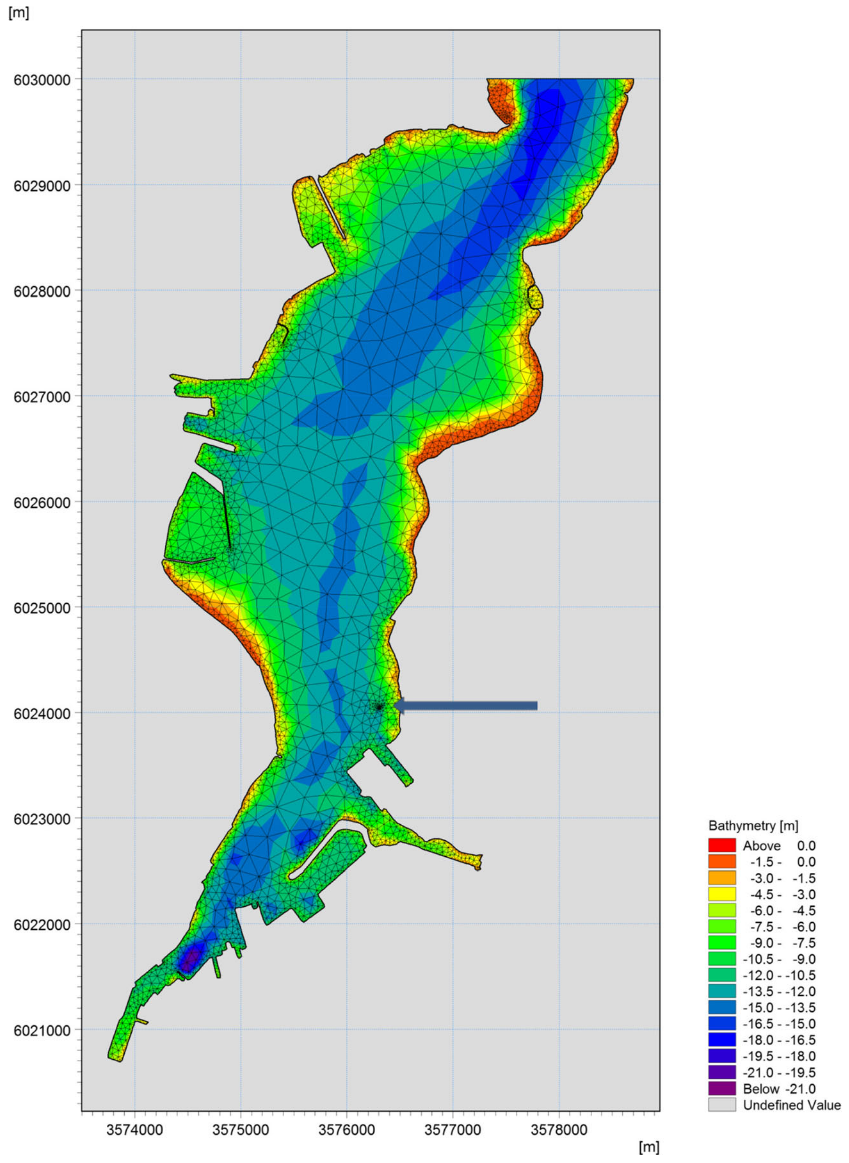


Fig. 6 Mesh and depth structure of investigation field Kiel Fjord with aquaculture site (ca. 10 m diameter)

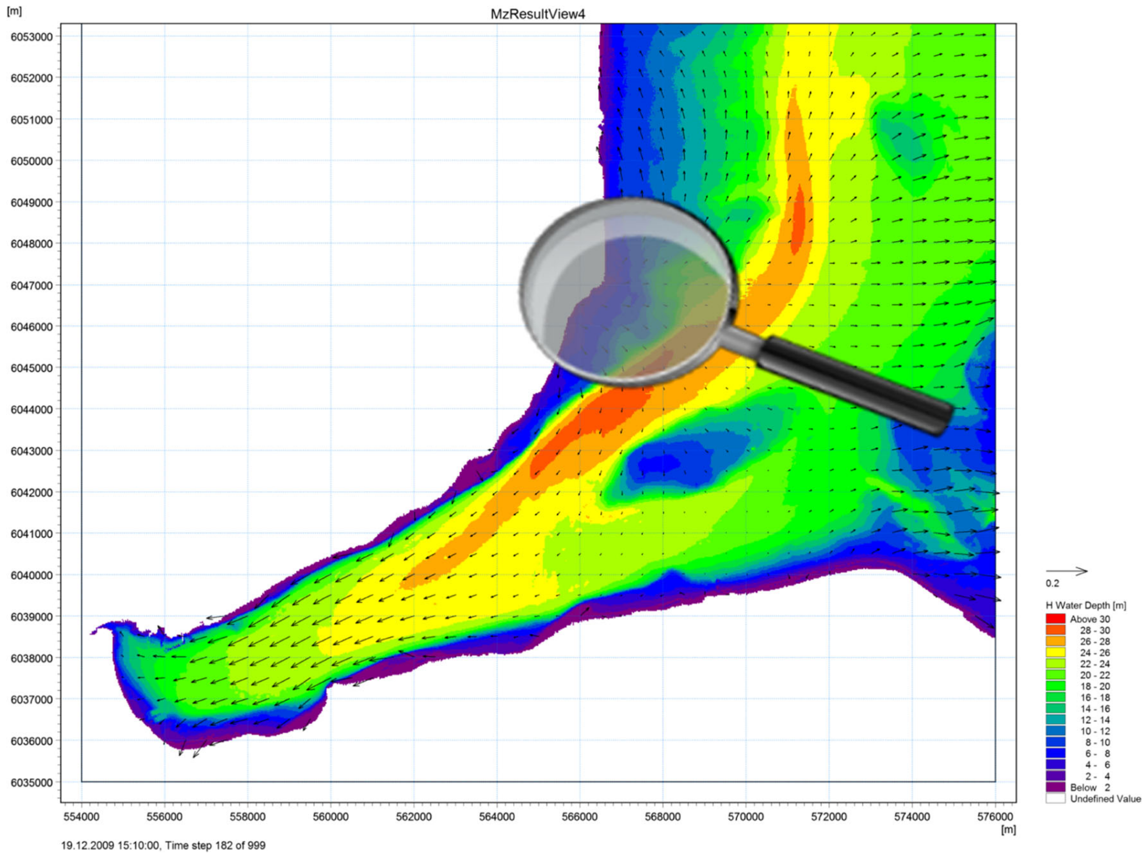


Fig. 7 Example of current conditions Bookniseck

MIKE21PT for faeces tracking

The MIKE21 Particle Tracking Model is used to simulate the transport and dispersal of suspended faeces. The horizontal range of the suspended particles depends on the settling velocity, water depth and the current velocity calculated in MIKE21HD. The settling velocity for faeces was between 0.02 m/s–0.06 m/s (Reid et al. (2008). We used 0.02 m/s as worst case scenario.

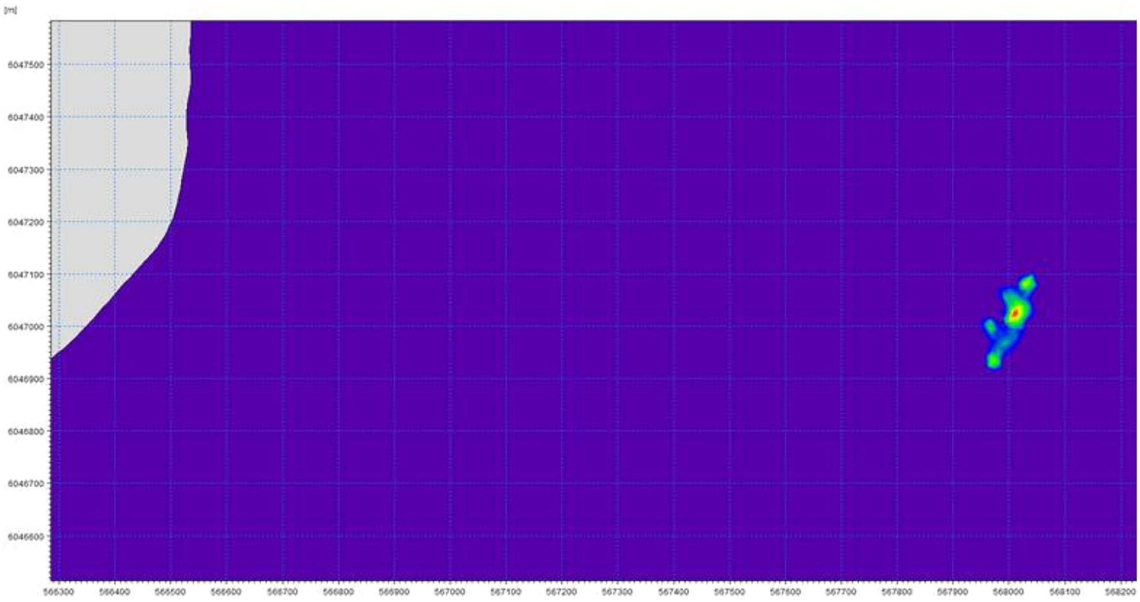


Fig. 8 Overview of faeces drift after 3 days

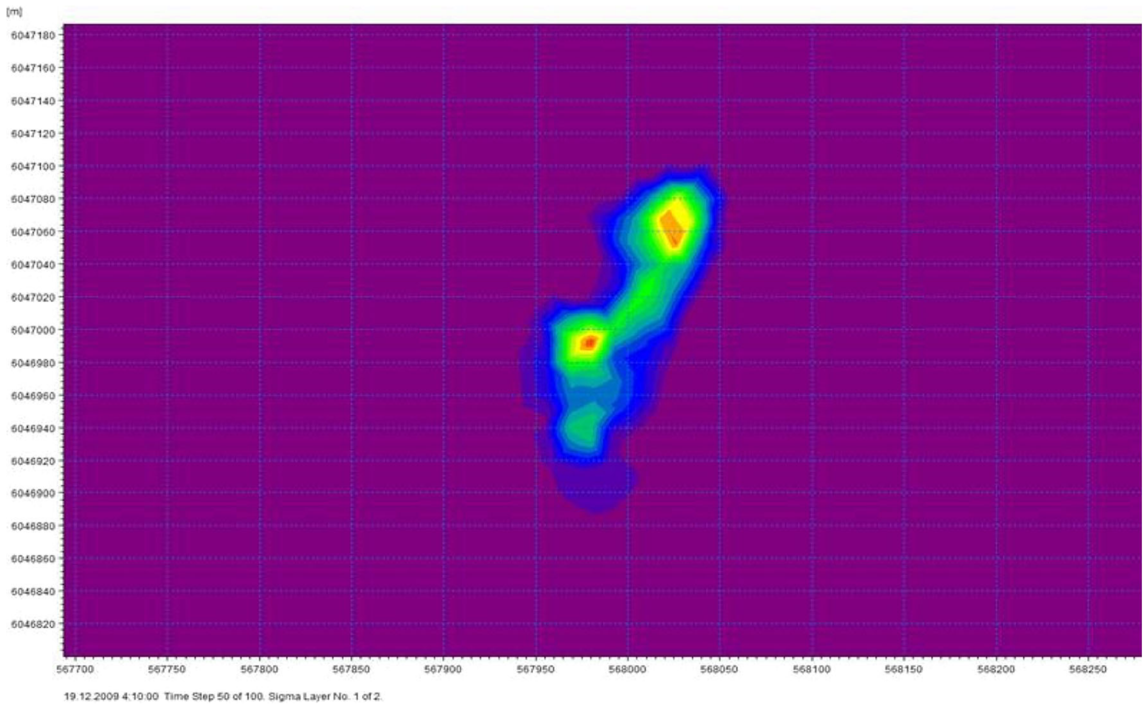


Fig. 9 Detail view of faeces drift after 3.5 days

Investigations areas

Two field sites were examined in this study (Fig. 4). Bookniseck, an open sea location, was studied by Ahrendt et al. (2014) and Haas et al. (2015) and there are many data for this site (tidal information, bathymetric data, background values etc.) available. The second field site was a small private aquaculture farm in the Kiel Fjord which was studied by students, mainly looking at benthic ecology. This site was already modelled (HD) by Neumann and Ahrendt (2013).

The natural hydrodynamic conditions there are completely different from the open sea site.

Bookniseck

This site is located at the northern part of the Eckernförder Bay (Fig. 5). The water depth at this expected aquaculture farm is between 15 m–20 m. The modelled area has two open boundaries, one in the North and one in the East. There are two tidal

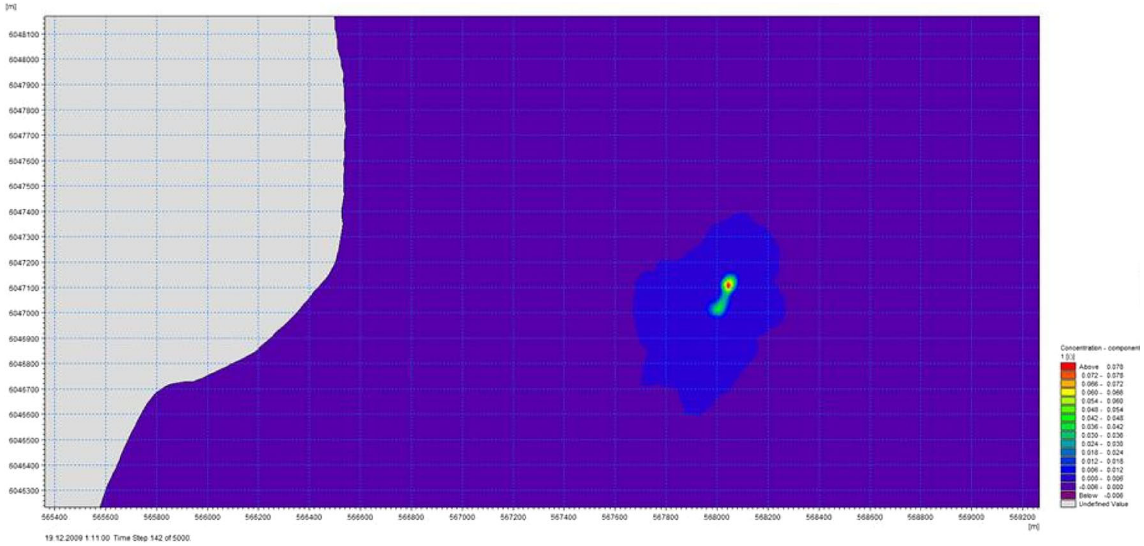


Fig. 10 Dispersal of N and P after 3 days

gauges, one in the North, Schleimünde, and one in the East, Kiel Lighthouse.

The Schleimünde tidal gauge was used for the boundary condition for the north boundary and Kiel Lighthouse for the east boundary conditions. The state of Schleswig-Holstein operates a long term measuring station for N and P inside this area. The grid components at the aquaculture site encompass an area of 25 m × 25 m.

Kiel Fjord

The Kiel Fjord site (Fig. 6) has one open boundary to the north. There is a tidal gauge in Kiel Holtenau in the northern part of the Fjord. A verification of the HD module was done in an earlier research project with a tidal gauge inside the area (Neumann and Ahrendt 2013). There is an existing fish farm with 8 cages, but only one cage

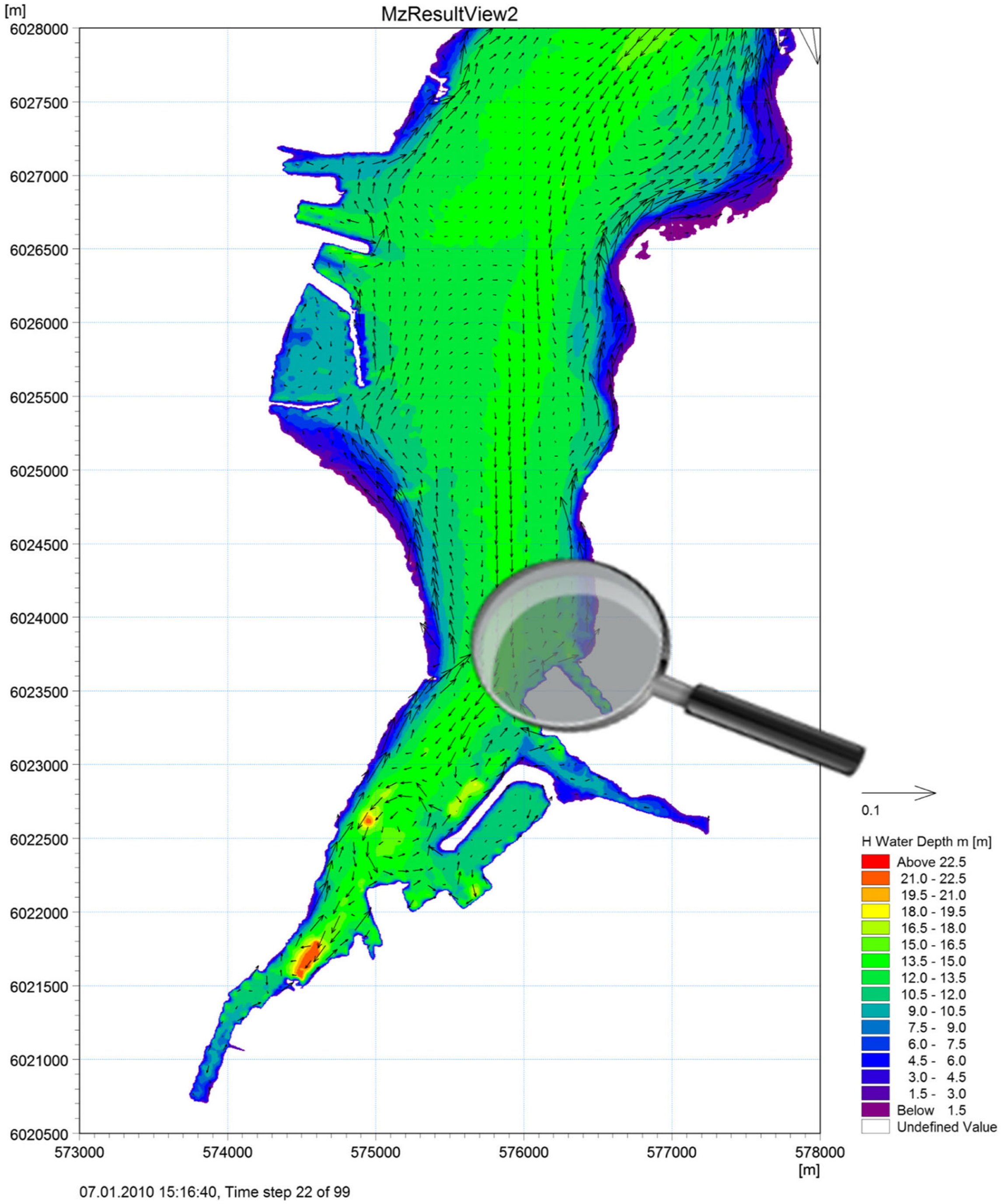


Fig. 11 Current conditions Kiel Fjord

is stocked and operational. The mesh in the location of the farm represents a 10 m × 10m grid. The water depth in that region is 5 m–6 m.

Results

Hydrodynamics Bookniseck

The current velocity varies between 0.01 m/s–0.1 m/s but velocities up to 0.2 m/s can occur. There is no predominant current direction. The current direction during the modelling was more or less parallel to the coast line. The change in the current direction, from North to South and vice versa, depends on the tidal phase. The wind conditions were set as constant for the seven day modelling period (Fig. 7). The water level fluctuation is ±20 cm, which is common.

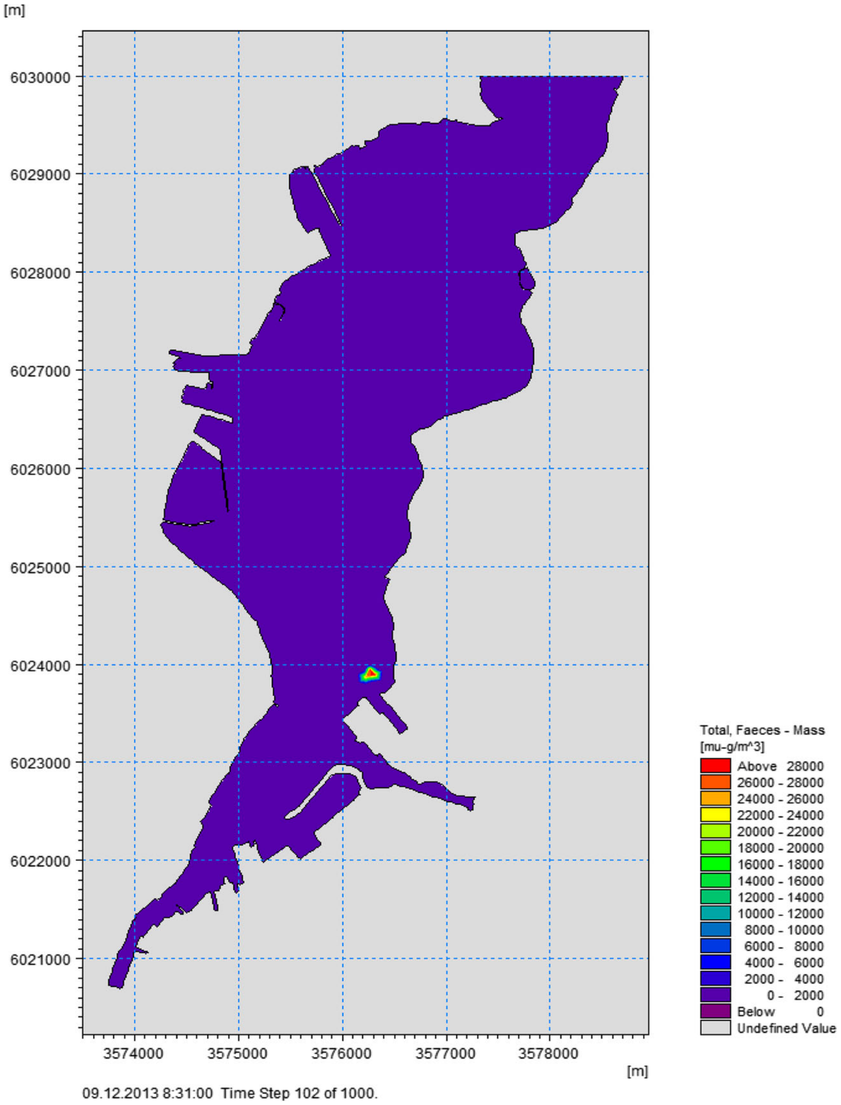
Faeces dispersal at Bookniseck

Based on the modelled hydrodynamic conditions, the faeces will be transported at most 200 m, i.e. 100 m to the North and 100 m to the South of the source. The west-east drift of the faeces is at most 50 m on either side of the source. The oscillation in the dispersal of faeces is largely driven by the tide (Figs. 8 and 9).

Dispersal of dissolved matter (N and P) Bookniseck

The dispersal of the dissolved nutrients N (1.5 g/s) and P (0.12 g/s) takes place relatively quickly. The values for N at a distance of 10 m from the farm are below 0.05 mg/l and at a distance of 150 m below 0.0005 mg/l. The values for P are even lower and at 100 m distance they are ca. 0.005 mg/l (Fig. 10). These values are far below the natural background concentrations and are well below detection limits ($<10^{-7}$ mg/l).

Fig. 12 Overview of faeces drift after 3 days



Kiel Fjord

Hydrodynamics in Kiel Fjord

The current velocity in Kiel Fjord varies between 0.05 m/s at most 0.15 m/s (Fig. 11). The predominant current direction is northward (outflow). The modelling covers a time period of 7 days with a tidal range of +70 cm to − 40 cm (including storm surge). The wind conditions were set constant over time.

Faeces drift in Kiel Fjord

The faeces are transported only a short distance in the water column due to the shallow water depth (5 m − 6 m). Faeces can be detected up to a distance of 75 m from the farm (Figs. 12 and 13) with minimal E – W drift.

Dispersal of dissolved matter (N and P) Kiel Fjord

The dispersal of dissolved nutrients N (0.15 g/s) and P (0.012 g/s) takes place relative quickly. The values for N at a distance of 100 m from the farm are below 0.004 mg/l and at 150 m below 0.003 mg/l. The values for P at a distance of 100 m are below 0.0003 mg/l and at 150 m below 0.00025 mg/l. The nutrients are transported to the North as a result of the predominant northward current (Figs. 14 and 15).

Findings and solutions

Faeces are transported only a short distance from the fish-farm source as a result of settling and current velocity and water depth. Faeces settle more or less directly below the cages with only a little drift to the sides.

Mineralisation of the settled fish farm faeces takes place, releasing nutrients, but this is a localized process. Dissolved nutrients released by the farm cannot be extracted directly; they must be fixed in organisms in order to be removed. Algae bind the dissolved nutrients directly whereas mussels do it through filtration. The elevated nutrient concentration inside and directly nearby the farm provides suitable conditions for cultivation of algae directly inside or nearby the farm.

The emission of dissolved nutrients and faeces is restricted to ten's or 100's of meters from the source. This allows us to design appropriate compensation measures. The drifting of

Fig. 13 Detailed view of faeces drift after 3.5 days

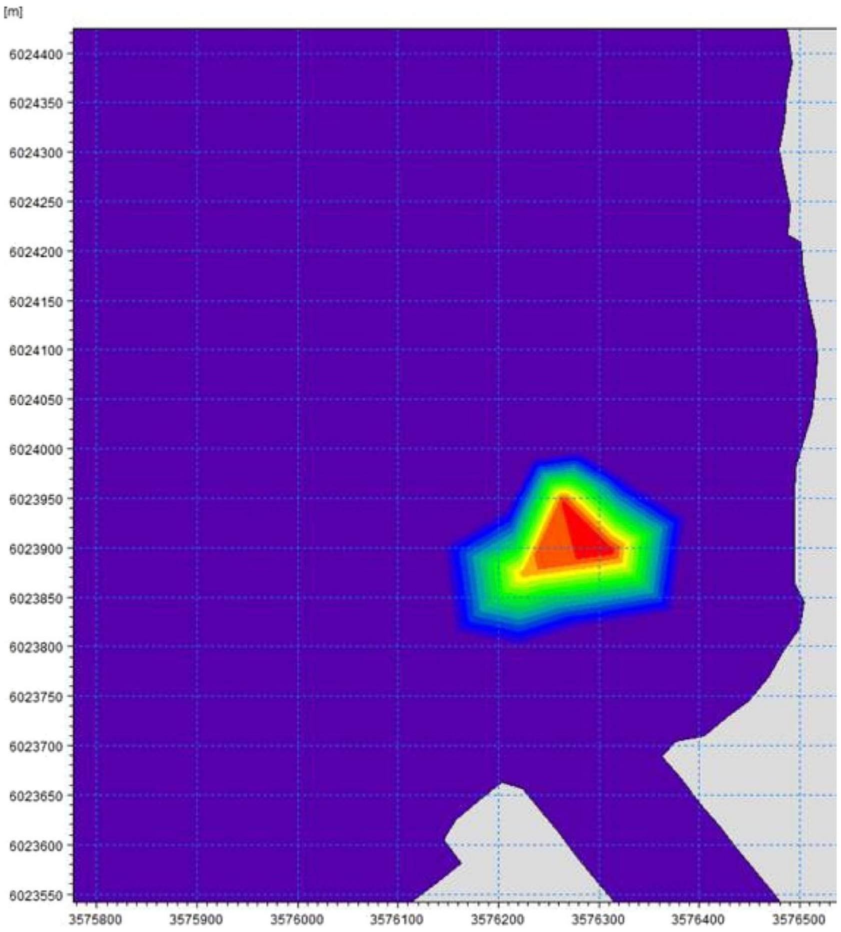
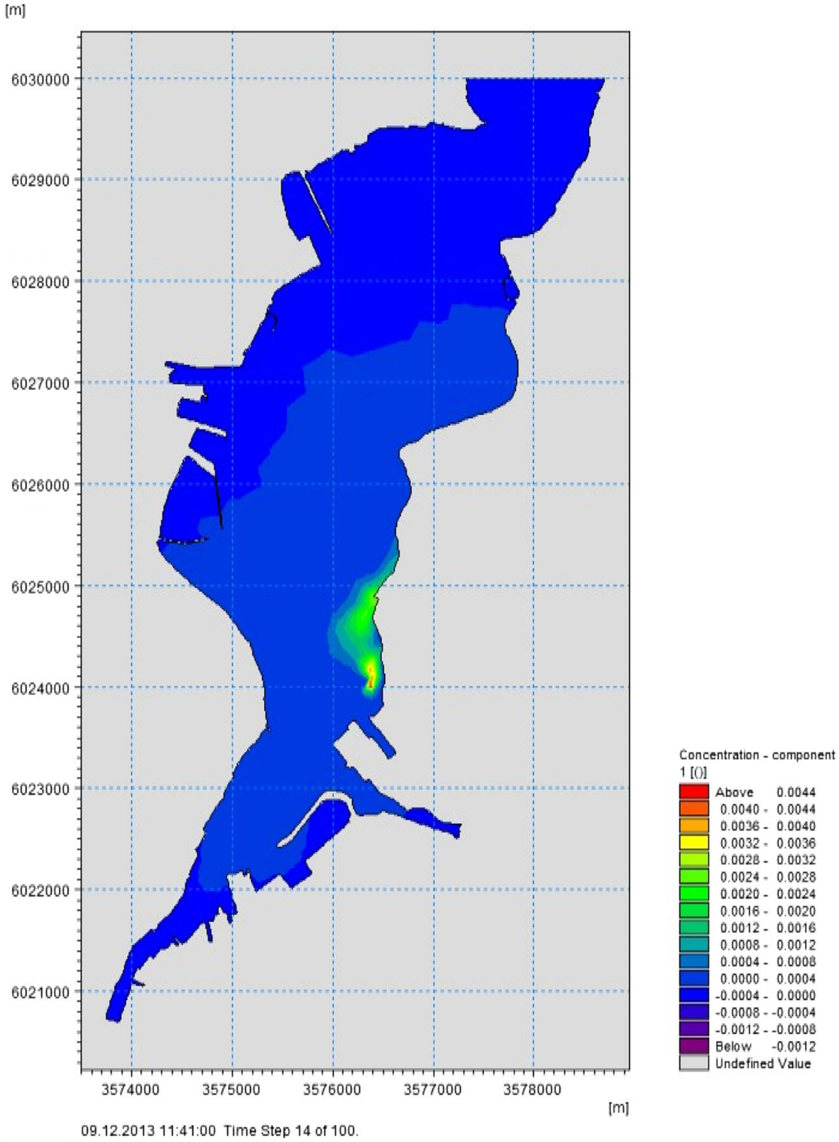


Fig. 14 Overview of dispersion of N and P after 3 days



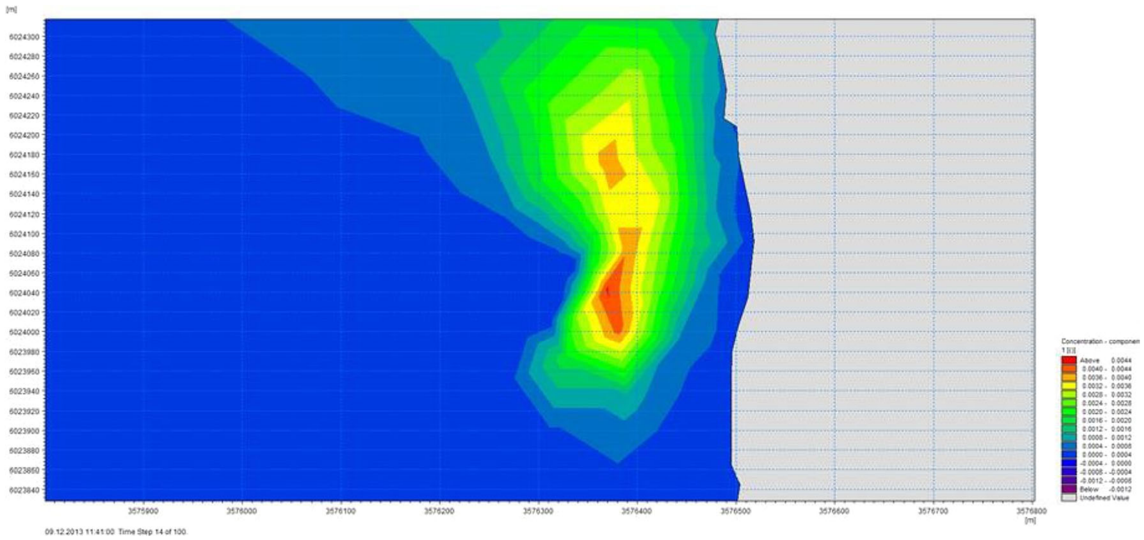


Fig. 15 Detailed view of dispersion of N and P after 3.5 days

faeces is relatively restricted. Faeces sink more or less directly below the cages or in close proximity. By manipulating the feed with heavy indigestible components we can cause the faeces to sink more rapidly and thereby minimize their drift far from the cages. A collecting device placed directly below the cages can help us capture a lot of this material (Fig. 16). The captured faeces can subsequently be extracted by concentrated and used as fertilizer, e.g. in agriculture. The nutrient enriched water pumped from the farm may be transferred to a basin with micro algae and the algae can harvested for further utilization. This pumping as well as the micro algae cultivation technology in open waters is a new challenge and still under development in Kiel Fjord. An additional advantage is that the pumping system can be reversed and oxygen can be pumped into the fish cages during oxygen deficit periods. A herbivorous fish, e.g. a mullet stocked in the outer net surrounding the (primary) farmed fish will help clean the nets and minimize the need for antifouling. The fine mesh net below the coarse net can be coated by nanotechnology to get an extremely hard and slippery surface to assist in the descent of detritus to the funnel and to reduce the rate at which fouling develops.

Pumping with frequent interruptions will lead to a vibration effect on the net and will assist in driving the fish faeces to the harvesting recepticle. Micro algae basins can be designed so that they are open at the bottom. Because microalgae need light and swim in the upper part of the water Column, they will not escape through the open bottom. The open bottom will improve the water quality. There is a space of 84,000m^2 inside such an aquaculture farm for algae (micro or macro) cultivation. Feeding and pumping (fish release faeces during feeding) should be executed during slack water, four times daily. The current velocity during "slack water" is lower than during other parts of the tidal cycle enabling the efficient utilization and fixation of unbound N and P by microalgae that may be subsequently harvested by the mussels.

Perspectives for marine aquaculture in Kiel Bay & Fjord

As our studies have shown, the sheltered coastal waters in Kiel Bay & Fjord are generally well suited for the cultivation of algae, mussels and fish. If carried out and monitored carefully, the negative environmental impact often associated with aquaculture installations, e.g. through excessive nutrient emissions, can be minimized. Algae and mussel ("extractive species") production may even have an additional "water cleaning" effect and could support the biodiversity of species and habitats. The economic potential for marine farming has been acknowledged at the political level and has raised expectations regarding this sector in recent years. Therefore, in 2012 the state government of Schleswig-Holstein outlined a "MASTERPLAN MARINE BIOTECHNOLOGY" (NORGENTA and DSN 2012) - a strategic framework for the development of marine technologies in upcoming years and decades. The main objective of the masterplan is to establish a legal and administrative basis to secure sustainable use and conservation of marine resources in the region. The

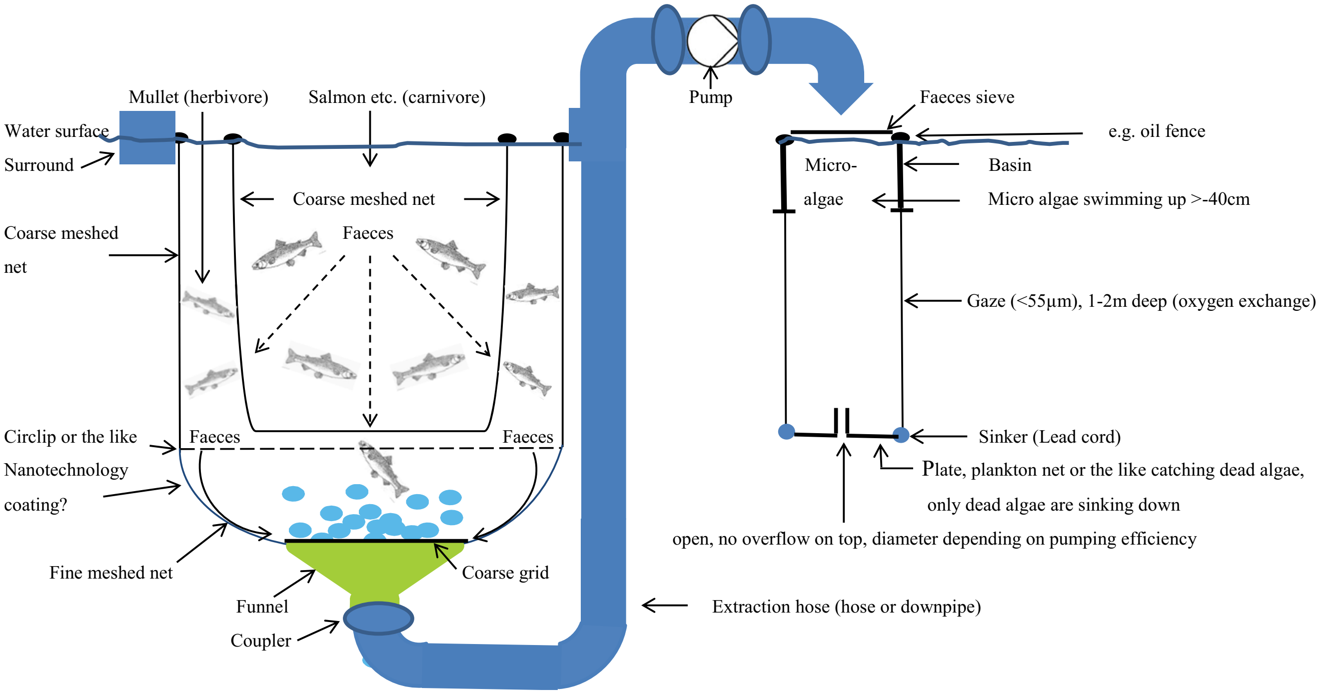


Fig. 16 Schematic diagram of an IMTA cage, not to scale

available resources range from the aquaculture products discussed in this paper to jellyfish, micro-algae and bacteria. Together these provide a variety of chemical and biological substances, e.g. collagen, omega3 fatty acids, lipids, proteins, carbohydrates etc. which are very valuable components in the production of pharmaceuticals and cosmetics, animal feed, biofuel, antifouling and other industrial products. The "Masterplan Marine Biotechnology" aims to reach far beyond the support of regional aquaculture, and sees this sector in the context of short- to mid-term sea-based economy. The political vision underlying this masterplan expects that "by the year 2030 the biotechnological use of marine resources will yield economic and food production benefits that are comparable to those gained from traditional agriculture. Through the development and implementation of sustainable technological solutions the marine biotechnology sector will make a significant contribution to environmentally friendly resource use, provide CO_2-neutral energy and ensure good health and livelihood of the coastal residents." The future development of the marine aquaculture sector thus faces promising perspectives, if a) the range of interests among coastal users and stakeholders can be reconciled and b) the administrative regulations governing the sector up to now will be simplified and harmonized.

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