MERMAID

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EIA of energy converters ➔ EIA Manual for MUOP (Multi use offshore platforms)

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1 INTRO TO D3.5 & D4.7: MERMAID - Environmental Impact Assessment

Conducting an Environmental Impact Assessment for Multi Use Platforms is an important crosscutting outcome of the MERMAID project. It has been recognized that both in the project description of work and the inception report elements of EIA is included in several of the work packages (WP3, WP4, WP5, WP6, WP7 and WP8). Especially, WP3 and WP4 contain related EIA elements, which are reflected in “Task 3.5. Conceptual environmental impact assessment for multi-use offshore platforms” and “Task 4.4 Environmental Impact Assessment and Habitat Modification”.

<u>This manual covers the two deliverables:</u>

D3.5 EIA of energy converters	**M44**
D4.7 Ecology Report on ecological consequences of alternative aquaculture farm designs	**M45**

➔ EIA manual for MUOP (Multi use offshore platforms) (D3.5 + D4.7)

To harmonize and avoid possible overlaps between EIA inputs described in different work packages and assure that the EIA is consistent with other WP´s that rely on information from this activity, it have been agreed that the main anchorage of the crosscutting EIA component will be in WP4. In order to address the different EIA elements the project partners have agreed that the development of a guideline for conducting environmental impact assessment for MUP´s will assure alignment between the different EIA related tasks.

The purpose of guideline is to provide an overview of key issues in the approach to assess the environmental impact of planned new marine aquaculture farms and offshore wind farms (OWF) and especially the so called Multi Use (offshore) Platforms (MUPs) where two or more - related or unrelated - activities are undertaken within a confined area. The guideline intends to assist with environmental impact assessment for the four MUP study sites proposed by the MERMAID project and provide guidance for future MUP´s initiatives.

Presently the EIA guideline is under development and a draft is placed both as a deliverable under D3.5 and D4.7, since this serves as specific output for these tasks (3.5 and 4.4).

2 Introduction

This report presents an overview of key issues in the approach to assess the environmental impact of planned new marine aquaculture farms and marine renewable energy installations (MREI) and especially the so called Multi Use (offshore) Platforms (MUPs) where two or more - related or unrelated - activities are undertaken within a confined area. The note is intended to be used to guide impact assessment of the four MUP cases studies in Mermaid.

The report builds on published reviews and guidelines and other key publications concerning impact assessments of MREI (with focus on offshore wind farms, OWFs) and marine fish farms and bivalve farms. These publications are listed in the Bibliography section. The report deliberately avoids the approach seen in scientific studies where all (likely and less likely) effects of MREI and aquaculture farming are listed and discussed. Instead, the report focus on impacts that have been documented in several studies and potentially affects the environment at a scale larger than the immediate area occupied by fish farms or turbine foundations. When specific impacts are not covered in reviews newer scientific is cited and listed in the Cited literature section.

The assessment method focuses on direct impact on the environment at production sites thus neglecting other resource inputs including energy, feed production, and access to land facilities. Another restriction of the report is that social acceptability of installations and any aesthetic degradation of the landscape are not included in assessment.

A common EU EIA directive was adopted in 1985 (and updated regularly with amendments; aquaculture included in 2012), i.e. *before* intense marine fish farming[1] became an integral part of the coastal economy in many regions in Europe, and *after* the intensive expansion in OWF in Europe[2]. The onset of the two activities seemingly, has had consequences on how the legislation was executed of within different EU countries. For aquaculture, execution of the EIA process in several countries depends on existing and sometimes unnecessarily bureaucratic frameworks, while EIA implementation for the “new” renewable energy activities such as OWF seemingly is more uniform across EU and in line with recent guidelines.

The most recently announced (February 2014) amendment to the EIA directive stress that impact assessments must take account of “new” environmental factors, such as biodiversity and climate change. Besides, future EIAs shall make “assessment methods clearer, facilitate public participation via a central web portal, and include beefed-up rules to prevent conflicts of interest and restrict recourse to exemptions”. Important improvements also include clearer attention a cumulation of projects (to prevent developers from splitting big projects into many smaller projects so as to stay below thresholds), and inclusion of hydro-morphological changes. The report will discuss potential

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[1] Marine farming of oysters and mussels has been carried out in 1 to 2 thousand years in Europe while intense marine fish farming is much more recent. Cage farming of fish in open waters was introduced in Europe in the early 1970-ies.

[2] The first OWF in Europe was established in 1991 but the large expansion took place after 2004.

cumulation (can add to impacts or reduce impacts) of different projects and activities taking place on a MUP.

3 What is an Environmental Impact Assessment?

The EIA process is an internationally recognized method of investigating the likely impacts of a development on the surrounding environment (including hydro-morphology, chemistry, biology in a broad sense) *before* the development has taken place, and for providing a structured environmental management and monitoring programs.

EIA provides a system of investigations, in which the risks of impacts happening - during establishment, operational and decommission - their magnitude are assessed and evaluated; mitigation and management measures applied to reduce impacts; and establishing a basis for a monitoring program to ensure the predicted impacts do not exceed defined environmental standards. Importantly, decisions must be based on sound scientific information, the process should allow all relevant stakeholders to make their comments on a proposal, and have their concerns and observations responded to, in the process of coming to a decision to approve or not approve a development.

Not all projects need to undergo an EIA process, as size of project, sensitivity of the area and magnitude of impact and risk, all are reasons to trigger onset of an EIA process. Whether or not a full EIA is required, there will be a minimum obligation to carry out an initial investigation or a “screening” of developments to determine if a more detailed assessment is required.

To our knowledge, all Offshore Wind Farms - established or planned – have gone through or must go through a full EIA, and for new marine aquaculture farms above a commercially viable size (e.g. exceeding a yearly production of 100 tons) EIA will be mandatory. It follows, that any commercial-sized MUP will need to go through an EIA process.

3.1 Transboundary impacts

If projects implemented in one Member State is likely to have significant effects on the environment of another Member State or two states are partners in one common project such as a bridge connecting the two MS, the EIA needs to be treated in a trans-boundary context, known as the Espoo Convention, which define specific rules for conducting an EIA of activities located on the territory of one contracting party, and likely to cause significant adverse trans-boundary impact in another contracting party. Recently, two fixed link projects connecting Denmark and Sweden (bridge and tunnel), and Denmark and Germany (tunnel) went through differing national EIA processes as well as the Espoo Convention involving Finland, Sweden, Poland and the Baltic states, because of potential impact on water exchange of the Baltic Sea (potentially affecting recruitment of cod).

3.2 Steps in an EIA process

The process involves an analysis of the likely effects on the environment, recording those effects in a report, carry out a public consultation exercise on the report, taking into account the comments when making the final decision and informing the public about that decision afterwards. Formally, the EIA process encompass sequential steps including: screening, scoping, examination of alternatives, impact analysis, mitigation and impact management, evaluation of significance, preparation of Environmental Impact Statement (EIS) report, review of the EIS, decision making and follow up. A list of 10 steps is shown below:

1. Screening determines whether an EIA is required for a specific project.
2. Scoping identifies of potentially important impacts (by establishing a Terms of Reference, ToR for the EIA).
3. Examination of alternatives selects the environmentally most desired policy option (e.g. establishment at alternative locations)
4. Impact analysis identifies and predicts the effects of the proposed project.
5. Mitigation and impact management establish measures to minimise important negative effects.
6. Evaluation of significance evaluates if the impacts (that cannot be mitigated) are acceptable (e.g. meets Environmental Quality Standards, EQS) to as compared to the overall benefits of the project.
7. Environmental impact statement (EIS) is documented in a report.
8. Review of the EIS assesses the quality of the EIS report (e.g. by authorities and their consultants).
9. Decision making approves or rejects the proposal.
10. Monitoring of impacts and effectiveness of mitigation measures check if impacts are within accepted/predicted range.

In the following three critical steps (2, 4, and 6) encompassing the major part of science and technology in an EIA are treated explicitly, based on examples from literature reviews and consulting reports (grey literature). Each step is discussed/reported sequentially for OWF, Aquaculture (fish and shellfish) separately, and in combination (MUP).

An EIA process must be objective, balanced and all changes should not be treated as being negative for the environment. Obvious benefits are reef effects of solid structures in some environments adding to biodiversity, but on the other hand introduction of solid structures may promote the spread of invasive species using structures as “stepping stones”.

3.3 Important impacts of offshore wind farms and aquaculture farms

Rule no. 1 "Prior to and during scoping phase of a project carefully consider the location of project area to minimize conflicts and major environmental impacts" - but of cause a project should not compromise majorly with sites having optimal conditions for wind energy extraction or aquaculture production as the value (economically and societal) of the new project may be significantly larger than the competing projects! Ideally, the “I was here first” attitude should not apply in a modern society!

An overview of potential conflicts with other interests is listed in Table 1 along with considerations for reducing such conflicts. Ideally, solving conflicts, final site-selection and licensing should be carried out in cooperation between coastal managers, licensing authorities and project holders.

Table 1 Overview of potential conflicts and considerations for minimizing conflicts that may arise from an unconsidered location of an offshore wind farm or an aquaculture farm

Issues	**Potential conflicts**	**Considerations for reducing conflict**
Nature conservation areas (Marine Protected Areas, NATURA 2000)	Loss of area or function of area, or disturbance of biota in the protected areas	Avoid sensitive areas or ensure that projects agree with the relevant protection and conservation targets
Areas of biological or ecological interest or value (habitats of rare or threatened species)	Loss of area or function of area, or disturbance of biota in the sensitive or ecologically valuable area	Avoid sensitive and ecologically valuable areas or ensure that projects does not affect the respective area and its biota negatively
Bird migration routes over sea	Disturbance of migration; risks of collision	Relocate; strong focus from NGO's
Archaeological sites	Loss of areas of archaeological interest; destruction of or damage to archaeological sites	Adjust planned locations of foundations, cables, anchoring
Navigation	Interference with free passage	Avoid established shipping lanes and anchoring sites; if appropriate, make provisions for shipping within and around project area
Recreational use	Restrictions to recreation and shipping	When possible allow for shipping within wind farms and around OWF and aquaculture,
Civil air traffic	Obstacle to air navigation in particular for low flying aircrafts	Avoid entry and exit lanes
Fisheries	Loss of fishing grounds. Increased steaming time. Economic loss.	Potential benefit for OWF for fish refuge, combine OWF and aquaculture
Military practice areas	Loss or restriction of areas	Avoid areas, look for solutions at political level
Gas and oil pipelines	Loss or restriction of areas available for routes; obstruction of maintenance and repairs; damage to existing pipelines	As necessary avoid pipeline routes; ensure sufficient space for maintenance or repair vessels
Submarine cables	Loss or restriction of areas available for cables; obstruction of maintenance and repairs; damage to existing cables	Avoid cable traces; allow for sufficient space for maintenance activities
Sand and gravel extraction	Temporary loss or restriction of areas	Avoid licensed extraction areas
Offshore oil and gas activities	Temporary exclusion or restriction of exploitation or exploration activities	Avoid licensed areas; enable sufficient space for exploitation or exploration activities
Disposal sites for dredged material	Loss of disposal sites; obstruction of disposal activities	Avoid disposal sites; use available information on disposal sites
Past disposal sites for ammunitions	Disturbance of past disposal sites (risk of detonation)	Avoid past disposal sites; use available information on sites; carry out appropriate consultation and surveys in the planning phase
Seascape	Visual impacts	Select location sufficient distances from shore, avoid sensitive vistas
Scientific research	Restrictions for scientific research	Avoid areas where important scientific research takes place

After a project site has been selected the remaining important impacts need to be identified and quantified. Environmental impacts of OWF and marine aquaculture installations differs in several aspects, notably both in the duration as impacts related to construction phase are most important for OWF, while main aquaculture impacts relate to the operational phase of aquaculture.

3.3.1 Identifying important impacts – Scoping Report

The EIA Directive and numerous guidelines all have long lists of potential impacts related to a new project. However, it needs to be stressed that all – even relevant - impacts are not equally important in a specific project and it is the aim of the scoping report to rank potential impacts after importance, and obtain acceptance for such prioritization from relevant authorities. Too many EIAs lack such focus and spend unnecessarily time and space on irrelevant issues.

3.3.2 EIA methods

To the extent possible, assessment methods shall be quantitative, predict the area affected, the level of effect and the duration of a specific effect level. Changes in conditions, features and biological components are evaluated against the so called “baseline conditions” established based on monitoring and/or numerical modelling.

Three types of assessment approaches can be used to quantify the impacts:

Numerical models can be used to quantify

- Structure-related impacts such as changes in hydrodynamic regime, waves and currents, changes in water column stratification, vertical mixing and associated changes in bottom water oxygen concentration.
- Shading effects of sediment spill on water quality (nutrient concentrations, chlorophyll-a, Secchi depth, oxygen concentration), on plankton ecology (primary production and zooplankton biomass) and on benthic vegetation
- Sedimentation of spilled sediment (from dredging) covering sedentary organisms
- Eutrophication effects (plankton growth, reduced transparency, reduced oxygen level in sediments and near-bed water below fish and shellfish farms) caused by nutrient release and particulate waste from aquaculture farms
- Spread of medicines and antifouling agents used in fish aquaculture described by advection-dispersion models and comparing predicted concentrations with Environmental Quality Standards (EQS)

A combination of quantitative and qualitative assessment can be used to:

- Evaluate the impacts on composition of phytoplankton, e.g. increased risks of Harmful Algal Blooms (HAB) caused by changes in nutrient availability and/or water column stability.
- Evaluate the impact of additional hard substrate (foundations and pillars in OWF), and estimate reductions in chlorophyll-a around structures due to establishment of sedentary filter-feeders on structures, and the additional oxygen production below pycnocline from macroalgae developing on foundations and piles.
- Estimate impact zones of noise from ramming activity (monopiles in OWF) and dredging (e.g. trailer-suction dredger) based on modelled transmission of noise and hearing thresholds of different species of marine mammals, turtles and fish.

A group of potential impacts cannot readily be assessed based on numerical modelling;

Such impacts tend to involve higher trophic levels, species with large individuals showing behavioral response to adverse conditions (e.g. marine mammals avoiding areas with high noise levels), and some impacts can be expressed over large areas, e.g. OWFs intercepting routes of migrating birds increasing risks of collisions, and additional hard substrate of OWF acting as "stepping stones” to promote the spread of invasive epifauna species. This type of impacts predictions usually is based on expert judgments, and should be based on sound scientific theories and preferentially back-upped by *in situ* studies. In contrast to numerical models that predict areas affected to various degrees, expert judgments usually will assess impacts in terms of probabilities.

3.3.3 Scale is important

Common to all EIA approaches is that scales of impact (area affected, duration) should be an integral part of any assessment (Fig. 1). For example, specific local effects of marine infrastructures such as OWF on recruitment of organisms may lead to changes in regional distribution patterns if multiple structures act as stepping stones for dispersal across coastlines for non-native species but not for native species as it has been observed in the MERMAID Mediterranean study site (Airoldi et al. 2015).Unfortunately, many scientific-based assessments often neglect the issue of scale and how scale can affect the outcome of an assessment. Obviously, extrapolating impacts from laboratory or near-field studies, e.g. sediment condition below a fish farm, to the level of ecosystem cannot be warranted if scale of impact is not taken account of. Scales inherently are integrated in numerical models and pressure maps such as distribution of excess concentration of suspended solids (dredging-related) or pharmaceuticals (release from fish farms) can provide information if water/sediment criteria are exceeded or not, but also guide the assessment of higher-order ecological effects, including cascading effects.

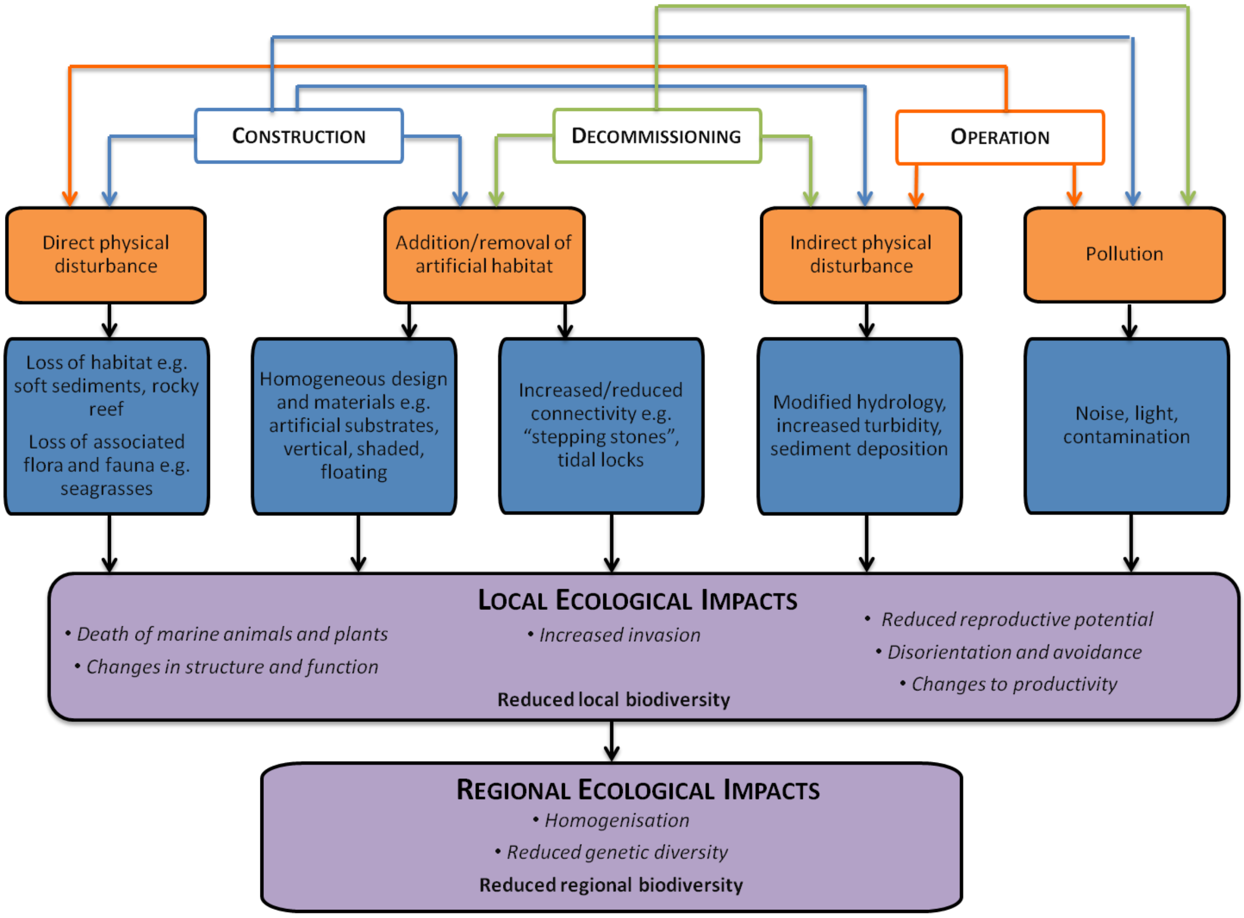

Figure 1 *Diagram illustrating the three engineering phases (construction, operation and decommissioning) that results in habitat modification (orange boxes). Examples of the physical/chemical changes are described (blue boxes) and potential ecological impacts identified at the local and regional scale (purple). From Dafforn et al. (2015).*

4 Impacts of Marine Renewable Energy Installations (MREI) - construction - operation

Compared to wave and tide energy converters the offshore wind sector is considerably more developed, having been operating for 3 decades with sufficient time to refine the associated impact assessment process, including verification (or rejection) of predicted impacts (e.g. Lindeboom et al. 2015). In contrast, the wave and tidal energy industry is only beginning to understand which type of impact assessment are necessary (Bonar et al. 2015).

The environmental conditions, features and biological components that may be affected by Offshore wind farms (OWF) or other MREIs such as Wave Energy Converters (WEC) and Tidal Energy Converters (TEC) - are hydrography (currents, waves, stratification and turbulence), water (chemistry, quality, pollutants), soil (seabed, sediment and features such as sandbanks), benthic vegetation (seagrass, macroalgae), fauna (benthic invertebrates, fish, turtles, birds, mammals), landscape (including coastline), humans and cultural heritage.

It is the task of the project owner to investigate the project area:

- to determine and assess the spatial distribution of conditions, features and biological components including their temporal variability (seasonal) and their status prior to project implementation (baseline study)
- to describe the effects that the MREI construction, operation and decommissioning of MREI, including the turbines, cables, scour protection might have on the features and biological components,
- to investigate and assess the actual utilization/exploitation of the area and any conflicts that may arise,
- to assess the sensitivity of the natural resources of the area,
- to assess the cumulative effects and all impact interactions the project might have with other projects (wind farms or other types of construction or activity e.g. aquaculture farms).

4.1 Construction phase

The most important environmental impacts during construction phase relate to sediment spill due to dredging for foundation and cable trenches and noise due to pile-driving. Whether sediment spill or noise impacts dominate depends on type of foundations; gravity foundations → sediment spill, monopiles → ramming noise.

4.1.1 Dredging and Sediment spill

Extensive dredging activities including the sediment spill and resuspension of sediment invariable will affect the light availability for phytoplankton and benthic vegetation due to shading from particles with potential effects on pelagic and benthic primary production. Besides, mobilisation of inorganic nutrients, contaminants and reduced substances (e.g. H_2S) in sediment pore water may lead to increased nutrient availability for plankton algae, exceedance of environmental quality standards for heavy metals and organic contaminants, and reductions in oxygen concentrations in water column. Spilled fine sediment can also overload the filtering apparatus in suspension-feeders, and the reduced transparency may affect visual predators and their prey. Expression of such impacts will depend on seabed characteristics including the content of fine particles (silt and clay), the organic content, and concentration of contaminants in sediments to be dredged.

Another issue of dredging-related sediment spill is a potential change in sediment characteristics (e.g. grain size) in area of deposition which can change habitat suitability of the resident fauna. Along with sediment characteristics the hydrodynamic regime will determine the extension and severity of spill-related impacts, i.e. in low-current environments impacts will primarily be of local nature and in high-current environments far-field impacts of lower intensity will prevail due to advection and dilution.

It is recommended to determine on-site contaminants values of the sediment to be dredged, along with the hydrodynamic regime affecting spill dispersal. Permits to dredging and disposal are under national regulations in EU with guidance from regional conventions (OSPAR – NE Atlantic, HELCOM – Baltic Sea, Barcelona – Mediterranean, Bucharest – Black Sea). Hence, contaminant levels and volumes to be dredged ideally will set limits on the maximal allowed spill and keep the associated contaminant impact at an acceptable low level.

Impact of spilled sediment depends on the relative increase in suspended solids and sedimentation compared to natural background values, the duration and area extent of increases, and the sensitivity of flora and fauna in the area. Data and 2-D maps with exceedance values of spilled sediment (concentration/turbidity, sediment accumulation on seabed, duration) can be estimated based on numerical modelling, where grain size distribution; spill rate, settling velocity, and critical shear stress for resuspension are important model inputs. When available, species sensitivity to increased sediment load and smothering usually are expressed in categories[3] (e.g. MarLin database), and to make species assessment operational spill pressure levels (concentration and sedimentation) also should be categorised (see Table 2).

Table 2 Example of pressure matrix for sediment load taking account of increase above natural level of total suspended solids (TSS) level and duration (weeks=wk) of exposure. Neglib.= negligible; v. High= very high.

Duration	1 wk	3 wk	6 wk	12 wk	>12 wk
TSS increase					
25%	Neglib.	Neglib.	Low	Medium	High
50%	Neglib.	Low	Medium	High	v. High
100%	Low	Medium	High	v. High	v. High
200%	Low	Medium	High	v. High	v. High
>200%	Medium	High	v. High	v. High	v. High

Based on recent comprehensive EIA's of OWF with gravity foundations the impacts from sediment spills have been characterised as minor and without significance primarily because sediments in project areas have had low content of fines. This fact is due to the shallow depth of the project areas (10-30m) and the seabed usually being erosional rather that depositional. Fig. 2 depicts the results of a model-based study concerning a 400 MW OWF established at 18-26 m depth. Except for the individual dredging pits for gravity foundations the average additional concentration of suspended solids was low and around 1 mg/l in project area. Considering a background concentration of 3-5 mg/l and the short duration of dredging period this increase in suspended solids was considered insignificant.

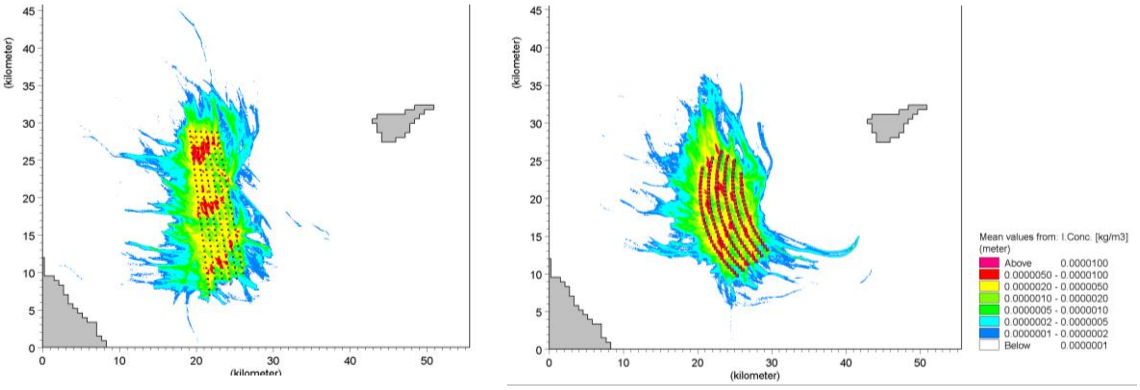

Figure 2 Average concentrations of suspended solids resulting from dredging operations related to two different wind farm layouts. Results from numerical modelling; from Energinet.dk (2009)

Dissimilarities in site conditions, season and sensitivity coupled with different dredging operations and technology used, will yield different conclusions for each studied site. For example, work done on the impacts of gas platforms in the Adriatic Sea suggest that impacts on sediments and associated benthos are much larger at deeper sites than shallower sites (Terlizzi et al. 2008). If sediment spill is considered insignificant (due to low content of fines in seabed material), the mobilisation of nutrients, toxic compounds and reduced substances, will be most likely insignificant too. Still, national regulations will likely require that a screening for content of fines and pollutants in sediments must be carried out prior to dredging.

In conclusion, at shallow waters and/or in non-depositional areas, the environmental impact of energy production installations from sediment spill resulting from dredging activity (gravity foundation and cable trace) most often will be of minor importance. At larger depth and/or in depositional areas, however, the effects could be significant, depending on local conditions. Grain size analysis of sediment cores will provide information if detailed impact analysis of sediment spills should be carried out.

4.1.2 Noise

Pile driving produces very intense underwater noise, potentially affecting marine mammals, fish and cephalopods. Depending on distance from the ramming activity noise effects can range from behavioural impacts (such as avoidance), hearing injury, and physiological stress to death. Recent studies have shown that the injury zone for fish larvae are very narrow around the piling locations, thereby only affecting a very small proportion of the larval stock. Noise is also produced by dredging (e.g. cutter-suction dredging) but noise levels are markedly lower and impact zones much more narrow. Pile driving noise for the installation of energy converters has its highest broadband at 100m and is above background noise up to a distance of 70km, which can cause behavioural changes in bottlenose dolphins up to a distance of 50km from a source at 40m depth (Bailey et al. 2010). Knowing the type of seabed, diameter of monopile (or dredger type), bathymetry, air pressure, salinity (presence and strength of pycnocline) and temperature in water, the noise propagation and levels can be predicted by modelling (Fig. 3). Such sound maps can be used together with data on the distribution and abundance of fish and marine mammals to provide an estimate of the number of individuals or proportion of stocks affected. The impact is then extrapolated using data on "dose-response" relationships known for individual species.

The bottle-neck to estimate realistic impacts is access to high-quality baseline data, i.e. abundance of key (protected) species including their seasonal variation in abundance.

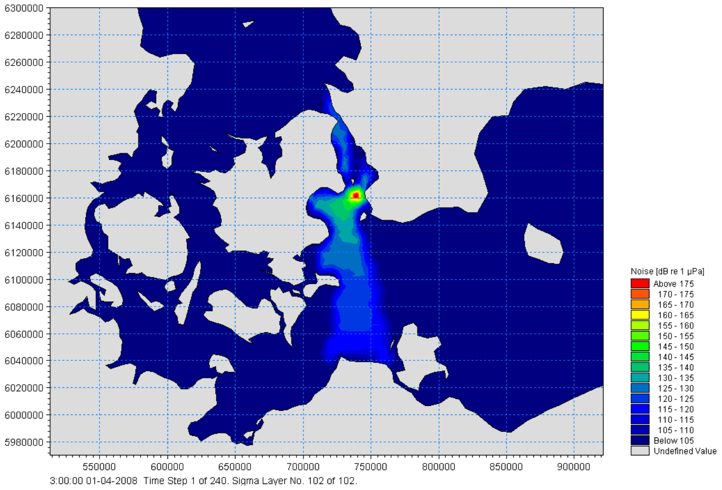

Figure 3 Hypothetical map showing the potential range and levels of noise produced by underwater pile driving - e.g. for the construction of an offshore wind farm - in the Inner Danish Waters. Model study by DHI

In conclusion, underwater noise from pile ramming has a documented negative impact on fish and marine mammals. An EIA for installation of energy converters shall include noise impacts at detailed levels if extensive ramming is required. If gravity foundations are used noise impacts probably can be assessed as a desk study.

4.2 **Operational phase**

Potential impacts during the operational phase are diverse but many impacts are poorly described and understood. A substantial knowledge has been gained from port-construction monitoring programs primarily carried out in Northern European waters. Unfortunately, several analogous studies have resulted in conflicting results.

4.2.1 Change in currents and hydrography

Individual MREIs will act as an obstruction to flow resulting in an increase in velocities in the immediate vicinity of the structure. A few pile diameters away from the pile, streamlines contract and at the base a so called horse shoe vortex is formed. Without scour-protection the “rotation” of current will cause scour. At the lee side of the pile lee-wake vortices will be formed. These mechanisms are the three types of local changes in the currents occurring (Fig. 4).
Besides underlining the need of scour protection the local changes in currents may help to understand the distribution of epifauna and macroalgae populating the piles, but in an EIA context these changes are insignificant because areas affected are small.

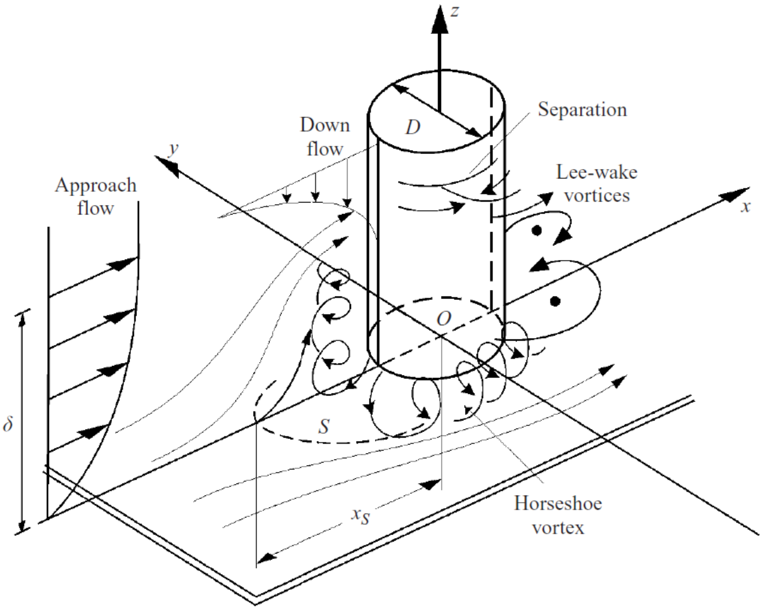

Figure 4 Overview of local current phenomena around a pile; from Roulund et al. (2005)

The large scale effects of an OWF differ from the local effects. The OWF as a whole acts as an extra roughness or a partial blockage of the overall current field. The blocked water volume is forced around the park which leads to a decrease in the flow inside the park and an increase in flow velocities on the sides of the park. The blockage depends on i) the ratio of Gab distance between plies (typically 600 to 1200 m) and the Diameter of a pile (6-10 m) and ii) the overall number of wind turbines in the park and the lay-out of farm. In a 400 MW OWF the predicted reduction in velocity inside the farm was less than 2 mm/sec (compared to a baseline depth-averaged velocity of 8-10 cm) and the increase outside the farm was less than 1 mm/sec (Fig. 5). The largest reduction was predicted in the near-bed water because of the additional blockage from the foundation and scour protection.

The predicted changes in current speeds were translated into changes in deposition of organic matter (originating from primary production) and abundance of suspension- and deposit-feeders inside and outside the OWF. These changes were small (< 1% change compared to baseline) underlining that the physical-mediated changes in ecosystem probably will be insignificant.

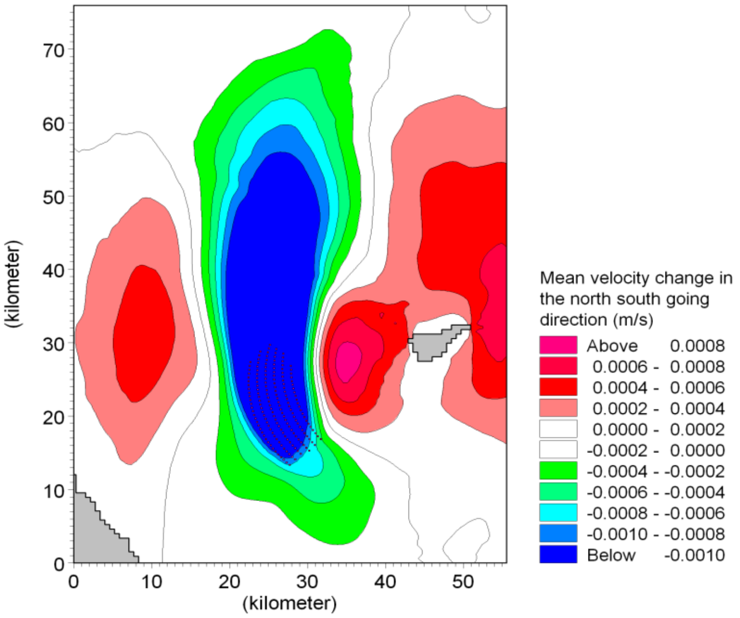

Figure 5 Modelled annually mean surface velocity changes in the north-south going velocity component in a 400 MW wind farm consisting of 2.3 MW turbines arranged in parallel arching rows. Green-blue colours indicate a velocity reduction and red colours indicate an increase in current velocity; from Energinet.dk (2009).

In conclusion, changes in currents at presently used layout (and future with larger Gab/Diameter ratios) of OWF can be considered as insignificant for the environment.

4.2.2 Electromagnetic fields

Underwater cables connecting an OWF to the grid ashore is an invariable necessity of an OWF. Marine mammals, sea turtles and fish (especially elasmobranchs) are sensitive to electromagnetic fields and use them for orientation, migration, reproduction, swimming behaviour and prey detection. One study has shown that power cables from an OWF could change the migration patterns of marine fish. But until confirmed in other studies impact from electromagnetic fields should be considered as a potential impact.

4.2.3 Change in habitats and biodiversity

The most notable biological change after establishment of an OWF is an increase in biodiversity due to the newly introduced hard substrate of the piles and stones. In eutrophic waters (NE Atlantic and Baltic Sea) sessile suspension-feeders, especially mussels and tunicates will populate the piles and several species of polychaetes, crustaceans and gastropods will establish in the 3-dimensional matrix of fouling organisms feeding on faeces produced by suspension-feeders. In oligotrophic waters sponges probably will be the dominating suspension-feeders on the hard substrate along with bryozoans, calcareous algae and serpulids.

The relative increase in hard substrate depends on size of individual wind turbines, the distance between turbines and the area of natural hard substrate already present in the OWF area. For a “typical” OWF consisting of large (3-6 MW) turbines established at 20 to 40 m depth the additional area of hard substrate (including scour protection) amounts to 0.3 to 0.6 % of the non-occupied seabed within the wind farm. Hence, if stones and boulders cover 1% of the seabed an OWF will increase the area of hard substrate by 50 % and by 5 % if 10 % of the seabed is covered by stores and boulders. Therefore, relative change in habitat for epifauna will depend on presence and amount of hard substrate already present on the seabed.

When OWFs are established at larger depths or when light at seabed is insufficient for benthic primary production, the increase in habitats for attached macroalgae can be immense, because the upper section of piles will be in the photic zone. Down-stream effects of macroalgal growth including availability of new substrate, increased food availability for herbivors and hide for juvenile fish can be important locally, but wide scale effects are unknown.

Organic enrichment in sediments around turbine piles must be expected due to sedimenting waste from suspension-feeders, and detachment of mussels and macroalgae leading to local reduction in oxygen concentration. However, model studies have shown that mesoscale (~ level of windfarm size) changes in near-bed oxygen is insignificant even during “worst-case” scenario (seabed located below pycnocline; current speeds < 2 cm/s) (Janßen et al. 2015).

In contrast to the predictable and uniformly observed fouling on hard substrate, observed changes within the soft bottom benthic community in established OWF have been unequivocal. In some studies increase in biodiversity of benthos and fish were explained by exclusion of fisheries. Some fish species are attracted to monopiles. In some studies harbour porpoise seem to prefer habitats within OWF, but in other studies harbour porpoise have not yet reached the former abundance. A recent study showed that seals may take advantage of OWF to forage by actively visiting structures where biomass of potential food items is high.

Divers and marine ducks were found to be the most vulnerable to offshore wind farms when taking into consideration flight altitude, duration, manoeuvrability, nocturnal flight activity, habitat specialisation and disturbance by wind farm structure operation and maintenance (ship and helicopter traffic) at varying degrees according to species (Furness et al., 2013). Extensive monitoring around OWF have shown that several bird species (diving ducks, razorbills) are displaced from OWF and rarely come nearer than 1-2 km from an OWF, while others (cormorants and gulls) seemingly are attracted to OWFs. It is unclear if habituation over time will change avoidance in diving ducks and razorbills.

In conclusion, the local biodiversity will increase locally when an OWF is established due to newly introduced hard substrate. Changes in biodiversity (including fish, birds and mammals) at larger scale will be very small because the area occupied by OWF at present size of developments is small. Cumulative effects can be expected if several large OWF are established in the same area.

4.2.4 Migratory birds and bats

Multi-million birds cross European Seas (Mediterranean, North Sea and the Baltic Sea) twice a year on migration. OWF established along or near migration routes may intercept migrating flock of birds with the risk of collision and associated mortality. In Northern Europe especially cranes and raptors seem to be most vulnerable species and most likely during foggy conditions when they may perceive an OWF for an island. Besides, many water birds theoretical are at risk because they fly within rotor height/the rotor swept area. However several aspects of migrating birds and bats and threats from OWF are unknown and the number of documented collisions is very low. Targeted studies using high resolution radar combined with visual observations and “particle-tracking” cameras are carried out around existing OWF to provide solid information on actual collisions and how environmental condition affects collision rates.

In conclusion, because trans-boundary impacts on migratory birds - many of them internationally protected – may be involved, new OWF should not be located along migratory routes.

4.2.5 OWF promoting spread of non-indigenous species (NIS)

Amongst the less cognized impacts of marine infrastructures are the large-scale regional effects on the connectivity of marine populations. If armouring and artificial structures are built in areas which otherwise have only soft sediment habitats such structures may act as stepping stones or corridors for hard-bottom species (Airoldi & Bulleri 2011), allowing spread of species into areas where they would not occur naturally. The consequences of such enhanced connectivity are poorly understood (Thomsen et al. 2015). On the one side increased connectivity could be a cost-effective way to enhance the conservation of threatened species and habitats, for example by providing new dispersal routes that facilitate their dispersal in response to climate changes (Thomas 2011). Alternatively, negative consequences, including the rapid expansion of “ephemeral” non-native species that are particularly well adapted to these environments could also result (Fauvelot et al. 2012). Identifying functional traits and resource use of the non-indigenous species will constitute initial means to improve the ability to predict ecological consequences of invasions.

Recent large scale monitoring efforts of ascidian assemblages on a variety of artificial structures in the North Adriatic Sea partially supported by MERMAID project has shown that artificial structures in sandy environments harboured almost exclusively non-native and cryptogenic species, therefore changing the relative distribution of non-native vs native rocky coastal species at regional scales

(Airoldi et al. 2015). Most native species of ascidians were virtually absent from any artificial habitats built along the extensive sandy coastlines of the North Adriatic Sea. This is despite the fact that many of these infrastructures have been in this region for > 60 years. Even when infrastructures were built along or in close proximity to rocky coasts, they only harboured 10 to 50% of the abundance of native species as compared to nearby natural reefs. At a regional scale, native ascidians remained substantially confined to the natural reef habitats, while artificial infrastructures built along sandy shores provided significant habitat enhancement to NIS and cryptogenic species, which were often the only colonisers on such habitats. Exposure had less prominent effects than predicted in influencing species distributions on artificial structures. On average the abundance of NIS was twice as large in sheltered than exposed artificial sandy habitats, and native ascidians were on average 4 times as abundant in exposed than sheltered artificial rocky habitats, although this pattern was not always consistent.

4.3 Decommissioning

Practical experience with decommissioning of OWF is non-existing and although some operators have developed strategies and diagrammatic plans the potential impacts of the decommissioning activities will to a large extent depend on the actual mode applied; e.g. if all structures are removed or if below-ground structures (monopoles, cables etc.) are left in place. Overall, a decommissioning process will include most of the activities carried out during construction, but likely at lower impact level and in case of mono pile the decommissioning noise surely will be of much lower intensity.

5 Impacts of off-coastal and offshore marine aquaculture farms

Aquaculture is the farming of aquatic organisms (fish, bivalves, crustaceans, seaweed) using various techniques, in order to increase the production of the organisms beyond the natural capacity of the environment, by regular stocking (e.g. mussels and macroalgae), feeding and protection of farmed fish from predators (fish being contained in cages).

The main environmental conditions, features and biological components that may be affected by an aquaculture installation are seawater (chemistry, quality, pollutants), soil (seabed, sediment including content of organic matter, nutrients, oxic conditions), benthic vegetation (seagrass, macroalgae, Maërl beds), fauna (benthic invertebrates, fish) and seascape in a broad sense.
Depending on size the installation of aquaculture facilities, mainly anchoring has low impacts on the seabed, and environmental impacts are connected to production rather than to the structure of installations.

It is the task of the project owner to investigate the project area:

- to determine and assess the spatial distribution of conditions, features and biological components including their temporal variability (seasonal) and their status prior to project implementation (baseline study)
- to assess the sensitivity of the natural resources of the area,
- to describe the effects of aquaculture operation might have on the features and biological components,
- to investigate and assess the actual utilization/exploitation of the area and any conflicts that may arise,
- to assess the cumulative effects and all impact interactions the project might have with other projects (aquaculture farms or other types of construction or activities).

Three types of aquaculture systems are discussed; seaweed production, shellfish production and fish production.

5.1 Seaweed

Exploitation of natural seaweed stocks has a long history along the European Atlantic coasts being used as food, feed for livestock, fertilizer, production of soap, iodine and hydrocolloids (e.g. alginate and agar) used as stabilizers in food and cosmetics. Today, the European harvest of natural stocks amount to 250,000 tons annually, but with 10 years negative trend due to declining stocks and harvest regulations caused by concerns of habitat damages. In comparison, only 1,000 tons is farmed annually in EU, primarily taking place in pilot-scale farms established in coastal waters.

The global seaweed market has a value of €8 billion with *farmed* seaweed for human consumption in SE Asia accounting for €6 billion.

Just as shellfish production seaweed aquaculture is a non-feed culture and instead of releasing nutrients, seaweed captures nutrients from water when producing, which is often considered being positive and will lead to improved water quality. Main bottle-necks in seaweed production are availability of space nutrients and cost-efficient growing and harvest systems. When planning for seaweed production care should be taken to select sites with high transparency, high nutrient availability and current speeds exceeding 10-20 cm/sec. Secondly, seaweed culture should not be established in areas where the culture will compete with (protected) natural populations of seaweed or seagrass for light and nutrients.

Despite growing interests for seaweed farming in Europe the production at present only constitutes about 0.01% of the entire European marine aquaculture. The seaweed farming industry is decades - if not centuries - behind agriculture in terms of level of mechanization, farming operations and infrastructure. Until a break-through in farming and harvest technique occur allowing European seaweed farmers to compete with production in SE Asia, commercial seaweed farming will be marginal in Europe.

5.2 Bivalve farming

Small scale oyster production was already practised by the Romans, but it was the fishermen in Normandy and Brittany that reintroduced oyster culture to compensate for a dramatic decline in fished stocks in mid-19th century. Today, oyster culture along the French Atlantic coast is one of the most valuable aquaculture assets in EU. Presently, three species-groups dominate the EU bivalve production; mussels, oysters and clams. The total value of EU bivalve production is €1.2 billion with about 90% being consumed within EU. Besides the local production member states import bivalves valued at between €250 and €300 million annually.

Depending on tradition and local conditions – e.g. tidal range - mussels, oysters and clams are produced on seabed, on poles ("moule de bouchot"), in small cages (oysters and scallops) or suspended in the water column attached to ropes or nets. Handling (e.g. seeding, thinning) is required during the production cycle, with the production of larvae and seed of oysters and clams in hatcheries following conditioning and spawning of brood stock. In contrast to oysters and clams, mussel seeds (juveniles) are collected and grown in coastal waters on seed collectors involving much lower investments and workforce. After sorting, juveniles are reintroduced into the water column (Fig. 6).

Filter-feeding bivalves filter, ingest and partly assimilate phytoplankton and other organic matter suspended in water. Bivalve farms are best established in areas where flux of prime food (phytoplankton conc. x current speed) is high so ingested phytoplankton is continuously being replenished. Undigested material is expelled as mm-large feces. In a dense mussel culture up to 300-500 g organic carbon/m^2 is expelled as feces daily.

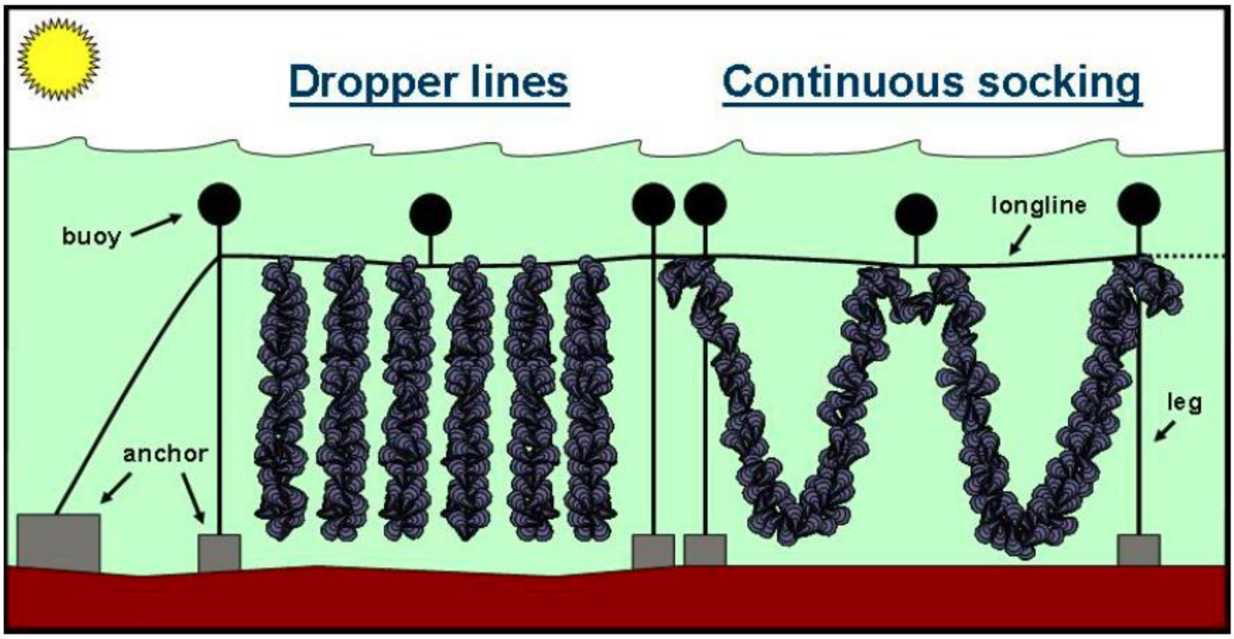

Figure 6 Mussel long-line system using dropper lines (left) or continuous socks (right).

5.2.1 Impacts and mitigation of eutrophication

Theoretical studies, numerical models and statistical models relating bivalve biomass to transparency or concentration of chlorophyll consistently show that high abundance/biomass of benthic filter-feeders such as mussels will increase transparency in the water column and thereby improve light conditions for benthic vegetation. Bivalves in suspended culture will have similar role on transparency but the scale of impact (often seen as an improvement) depends on the size of culture. Along with the removal of nutrients (nitrogen and phosphorus) in eutrophic environments when mussels are harvested the improvement of light conditions are considered as a beneficial role of suspended bivalve farming.

An obvious potential negative impact of large suspended bivalve farms is the high organic load of sediments below farms (as in fish farms). Depending on depth and current speed biodeposits may accumulate on seabed (especially in deep water and under low current speed regime) resulting in de-oxygenation of sediments and changes in the benthic invertebrate communities, typically a reduction in biodiversity and increase in opportunistic species (McKindsey et al. 2011). In shallow waters (e.g. below 20 m) in exposed environments deposits will disperse over large areas and the oxygen demand being diluted and only causing minor problems. The impact of deposition below mussel farms is analogue to waste deposition below fish farms and impacts can be predicted by numerical modelling (see fish farming).

Like mussels and oysters growing in dense assemblages on the seabed, rope culture can be seen as 3-dimensional habitats providing foraging and refuge opportunities for different species among invertebrates and fish, and as in mussel and oyster reefs on seabed, the abundance of sedentary and motile invertebrates is high in a suspended mussel culture nourished by faeces from mussels. Surely, a mussel farm will lead to change in local communities but above a sandy seabed without natural hard substrate biodiversity will increase. Suspended shellfish farms may also provide a novel habitat for colonisation by fouling communities. Once colonised, mussel and oyster farms may act as a "reservoir" for subsequent spread of unwanted such as non-indigenous species to the wider environment.

A mussel farm will act as a local resistance to flow resulting in reduced velocities within the farm and slightly higher velocities outside and below the farm. Like currents being attenuated waves passing through a farm will be dampened and depending on farms extension a "shadow" of reduced wave height may be seen 100 m or more downstream the farm. Significant changes in hydrodynamic regime may have secondary effects on sand transports along nearby coasts but such scale changes of the hydrodynamic regime in an area will be possible if farms occupy, say 5% of the area.

In conclusion, obvious negative impacts of suspended mussel/oyster farming on seabed can be reduced if farms are located in exposed areas where near-bed currents and shear from waves regularly erode, resuspend and disperse waste. With the exception of farms acting as stepping stones for spread of unwanted organisms in some areas, most other environmental changes can be seen as positive for the environment or without significance.

5.3 Fish farming

Modern finfish farming in marine waters began its expansion in 1960-ies and the annual production has now reached 430,000 tons in EU. Five finfish species - in decreasing order - salmon, seabream, seabass, rainbow trout and turbot - dominate the marine production accounting for 85% of the production volume and value. The cold-water salmon and trout are produced in the NE Atlantic region while seabream and seabass are produced in the Mediterranean. After raising larval and juvenile stages in land-based facilities salmon, seabream, seabass and trout are grown in cages in the sea. Depending on species, feed quality and environmental conditions – primarily temperature - outgrown fish can be harvested from 8 month to 2-3 years after they have been stocked in cages.

Most EU fish farms are located near the shore, typically in embayment's offering some protection from waves. Over the past decades both size of cages and farm has grown larger, and the producing companies have increased by consolidation and acquisition. To avoid competition for space with other coastal activities, large fish-farming companies move their farms to offshore locations where environmental conditions can support large farms. Such large farms can further increase efficiency by adopting automated or semi-automated feeding from barges and online monitoring of environmental conditions, feed-loss and well-being of the fish.

In contrast to marine renewable energy installations the environmental pressures related to fish farm establishment is considered to be small and insignificant compared to the pressures and potential impacts realized during the operation of the farm. During the anchoring process, some disturbance of seabed will occur but the area affected will be small.

Being an environment with a very high standing stock of domesticated fish (5-10 kg/m^2) that are fed intensively with “imported” feed, treated with pharmaceuticals to control infections a fish farm site differs majorly from a natural coastal or offshore environment. If established at suboptimal sites and/or managed improperly both cultivated fish and the environment may suffer. A graphic overview of potential impacts on the environment, including water quality, sediment quality, toxicity, benthic habitat modification, genetic interaction with wild populations, transfer of disease and parasites to and from wild populations amongst others is shown in Fig. 7 and listed in Table 3.

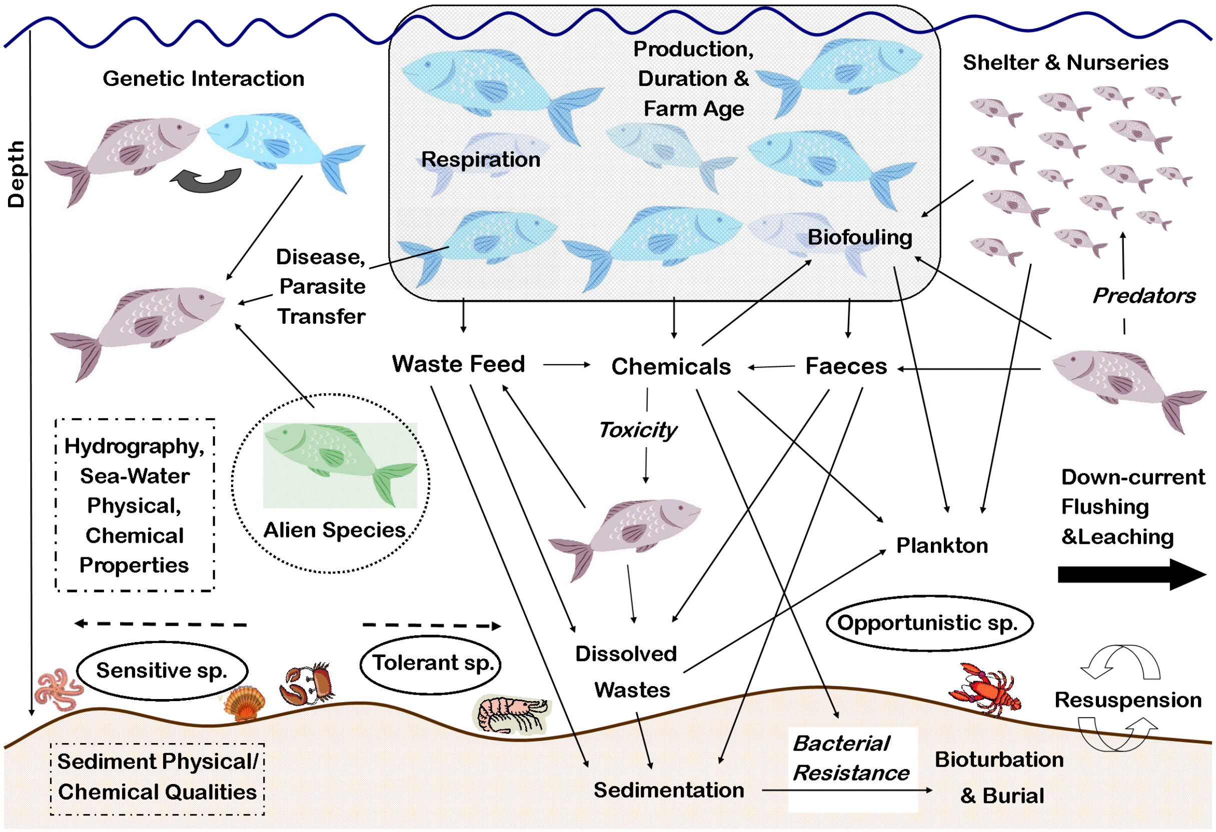

Figure 7 Environmental impacts of fish cage aquaculture (from Mermaid WP6, D6.3)

Table 3 List of environmental pressures, associated impacts and means to quantify and mitigate impacts in marine fish farming.

Pressure	**Impacts**	**Quantify / mitigate**
Seabed loads with particulate waste	Accumulation of org. matter and nutrients De-oxygenation of sediments, H_2S evolution Change in benthos composition	Calibrated numerical modelling / select production sites with sufficient shear stress to avoid permanent accumulation
Release of inorganic nutrients	Eutrophication: algal blooms, reduced transparency, light limitation in benthic veg.	Calibrated numerical modelling / select sites with high oxygen availability
Pesticides, medicines, biocides	Exceeding EQS, impact on benthic organisms, development of immunity in benthic bacteria	Calibrated numerical modelling /
Escapes	Escapees interbreeding with wild fish may lead to losses of genetic variability, with risks of reduced fitness and performance outside a cage	Expert evaluation / inspection of cages
Pest transmission to wild stocks	Increased mortality in wild stocks	Risk modelling / expert evaluation
Pest transmission to other farms	Epidemic spread of disease in farmed area	Connectivity / risk modelling / expert evaluation
Attractant to wild fish population	Increased sequestering of particulate waste	

5.3.1 Organic load of sediments

Processes and effects of organic load below fish farms resulting from sedimenting particulate waste probably are the most common environmental studies carried out at fish farm sites. Particulate waste consists of uneaten feed, faecal pellets as well as detached debris from fouling of the net cage structures. Severe accumulation can cause major changes in the structure and function of benthic ecosystems locally, often leading to low diversity of the benthic fauna and flora. At insufficient oxygen availability (i.e. due to low near-bed currents) sulphide will accumulate in sediments, organic matter become sequestered by microbial processes rather than by fauna and ammonia and phosphate will be released high rates from sediments potentially fuelling primary production with risks of negative feed-backs such as harmful algal blooms affecting the cultured fish.

By careful considering the hydrodynamic regime at potential production sites benthic impacts largely can be avoided. High current speeds in the near-bed layer will prevent sulphide accumulation and nutrient release from sediments, while regularly occurring periods of high shear stress on seabed will disperse the organic-rich surface sediments promoting fauna-mediated aerobic degradation of waste.

Benthic impacts (organic carbon accumulation, oxygen uptake, sulphide production and accumulation) of a planned aquaculture production can be estimated using calibrated numerical models encompassing detailed hydrodynamic description, advection-dispersion, water quality description, waste settling and degradation etc. Fig. 8 shows an example of predicted change (increase) in oxygen uptake in sediments after expansion of aquaculture production from 850 tons rainbow trout/year to 6,500 tons/year. Near-field (at farm area ~ 0.3 km^2) increase in oxygen uptake amounted up to 20 gO_2 m^{-2} y^{-1}, while far-field (> 1 km from farms) impacts typically varied between 0.5 and 5 gO_2 m^{-2} y^{-1} (~1-5% increase above baseline uptake).

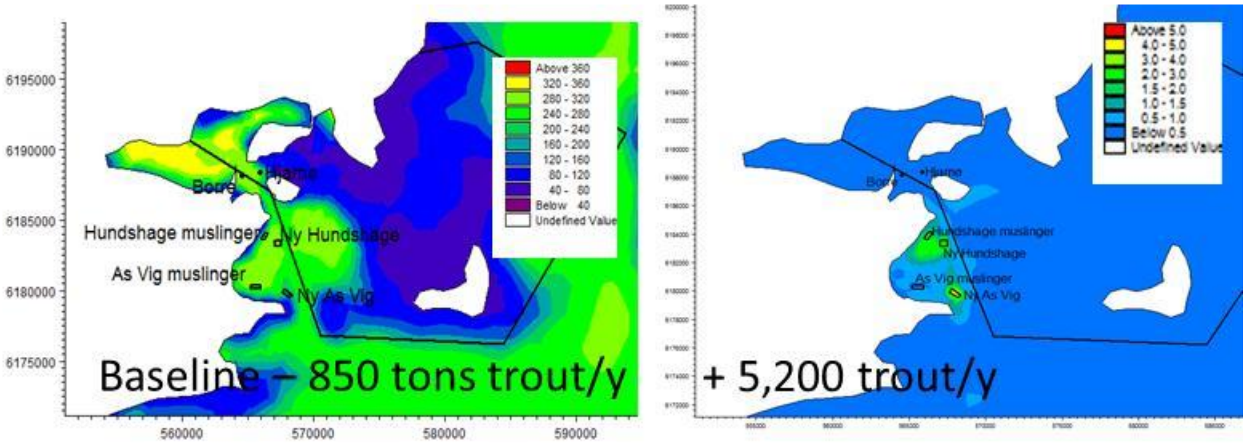

Figure 8 *Modelled "baseline" condition of yearly oxygen uptake in sediments (left), and predicted additional oxygen uptake after an expansion of trout production by 5,200 tons (right), from EIA study in Denmark by DHI*

In conclusion, negative impacts of suspended waste on seabed below fish farms can be reduced if farms are located in exposed areas where near-bed currents and shear from waves regularly erode, resuspend and disperse waste. If data on current speed is not available examination of seabed characteristics such as grain size and degree of sorting can provide information on if the seabed is erosional (medium grain size > 300 µm) or depositional (medium grain size < 150 µm). Depositional areas should be avoided.

5.3.2 Release of inorganic nutrients and eutrophication

Besides producing particulate waste individual fish releases nutrients as dissolved inorganic nutrients through excretion (NH_4 and PO_4 and dissolved organic phosphorus), with NH_4 being the main waste component of nitrogen. Often, coastal and offshore waters are nutrient (nitrogen) limited and inorganic nutrients released from a fish farm are quickly assimilated into primary producers stimulating production.

Overall, the capacity of a pelagic ecosystem to sequester inorganic nutrients released from a fish farm depends on two processes; hydrodynamics, i.e. dilution of excreted nutrients and uptake in primary producers and further transfer to higher trophic levels. Large fish farms require high dilution rates so that nutrient concentration will not exceed the assimilative capacity of the pelagic ecosystem. When dilution rate is low compared to nutrient release concentration of phytoplankton tend to accumulate because the capacity of higher trophic levels to sequester phytoplankton may be exceeded. In effects, eutrophication signs such as increase in primary production, reduced transparency and oxygen deficiency at seabed may develop. Fig. 9 shows the predicted increase in yearly primary production resulting from expansion of fish production from 850 tons to 6,500 tons and establishment of a mussel culture. At most primary production increases by 15 gC m^{-2} y^{-1} from ca. 200 gC m^{-2} y^{-1} under baseline conditions.

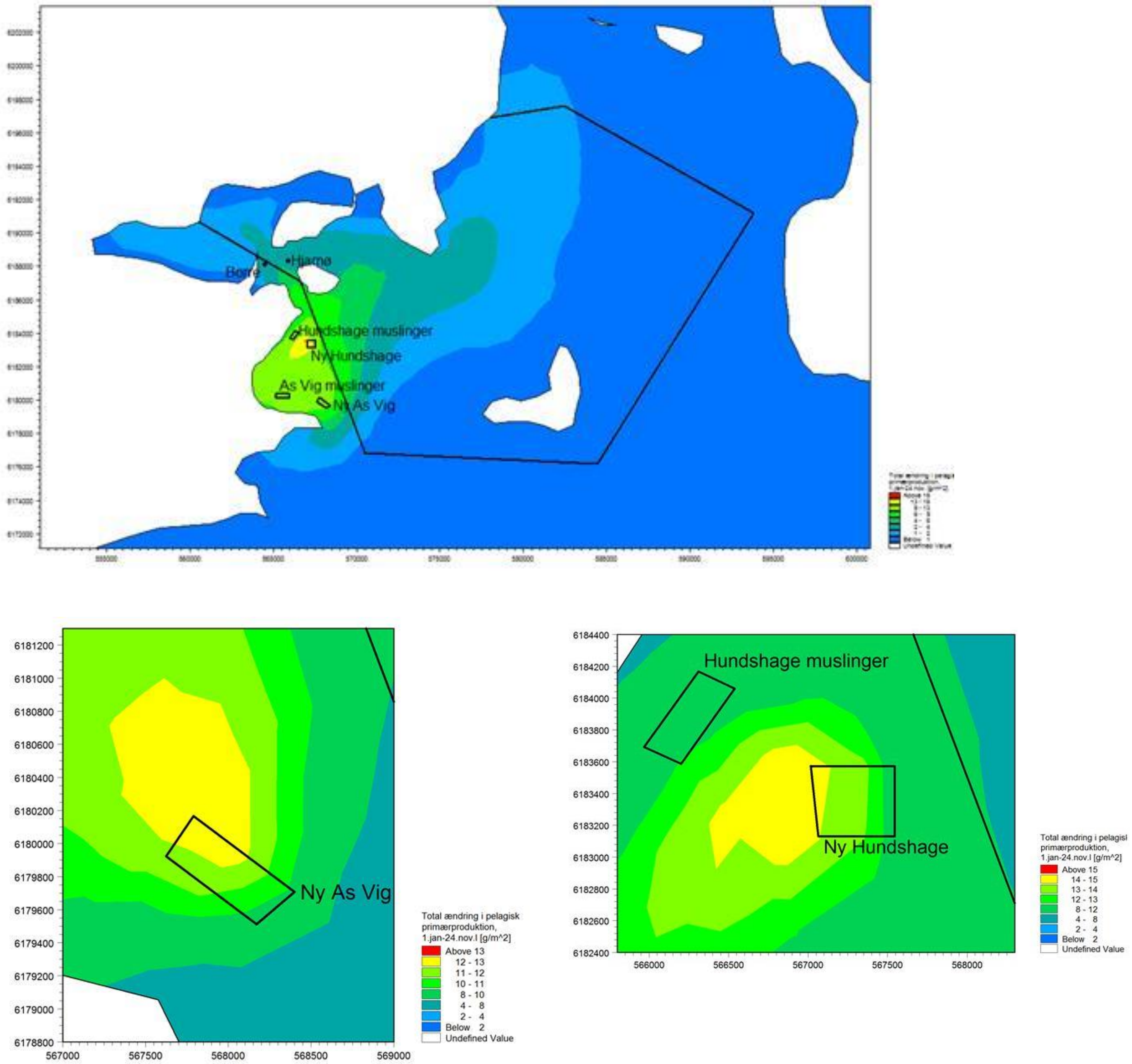

Figure 9 Predicted increase in yearly primary production around two fish farms being enlarged from 850 tons to 6,500 tons and new establishment of 2 mussel farms (upper panel). Details are shown in lower panel. From EIA study in Denmark by DHI

In conclusion, negative impacts of nutrient release such as eutrophication within or in vicinity of fish farm area can be reduced if farms are located in areas where average currents speed is *sufficiently high to disperse released nutrients to levels not exceeding background levels by more than 5-10%. Generally, the capacity of the ecosystem to assimilate additional nutrients from a large fish farm (≈ 1,000 tons/y) would not be exceeded if average current speeds are larger than 8-10 cm/s.*

5.3.3 Environmental impact of medicine and biocides

Medicines and insecticides are used in feed aquaculture to fight infections and pests, and biocides such as copper are used to control biofouling on nets. Depending on resulting concentrations release and loss of medicine, insecticides and biocides may be harmful to non-target aquatic life and to protect the environment environmental quality standards (EQS) and water quality criteria have been developed and are adopted in some countries. Hence, documentation that use of biocides and medicines will not violate accepted standards is an integral part of an EIA for new fish farms.

As a first approximation one can assume that all medicine given in feed to infected fish will be released in dissolved form to the environment within the period of treatment (typically 7 to 10 days). Surely, such assumptions will result in a “worst case” scenario especially if the release is implemented during a calm period with low currents and minimum dilution condition. Using such approach the concentration in water outside the fish farm area can be estimated using hydrodynamic model where medicine (e.g. oxolinic acid) is added as a conservative tracer at the centroid of each farm or at positions for each cage. To take account of cumulative impacts medicine sources are implemented for all fish farms located within the same coastal area (see Fig. 10). Hence, by this approach it is (unrealistically) assumed that all farms will treat their standing stock simultaneously, again underlining the conservative approach.

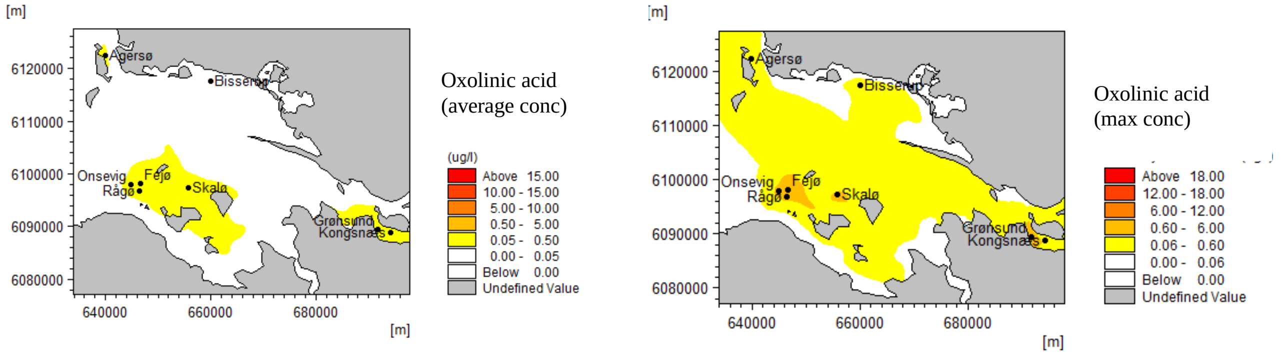

Figure 10 Modelled concentration of oxolinic acids in a coastal area with 8 fish farms treated simultaneously; average concentrations (left), max concentration (right). Total yearly trout production amounts to 3,050 tons in the area; from EIA study in Denmark by DHI.

The predicted concentration of oxolinic acid can then be compared to water quality criteria (max allowed conc.: 18 µg/l, average conc.: 15 µg/l). As seen in Fig. 10, the predicted concentrations are far below water quality criteria. Using the same calm period concentrations of other medicines allowed/used in farms and biocides (e.g. Cu) can be predicted by varying the source strength relative to oxolinic acids and resulting concentrations compared to their water quality criteria or the environmental quality standard (for Cu).

In conclusion, use of medicine, pesticides and biocides in fish farming may give rise to environmental impacts. However, environmental standards and water quality criteria are available for most substances which take much of the guesswork out of an impact assessment. Proper selection of production sites i.e. avoiding protected areas with limited dilution generally would allow fish farmers to use medicine at prescribed doses without exceeding environmental criteria and without ecosystem impacts.

5.3.4 Escapes and losses of genetic variability in native stocks

Escape of caged fish from fish farms can constitute a threat to natural biodiversity in marine waters. Through interbreeding, escaped fish may weaken the genetic integrity of native populations thereby decreasing their overall fitness. Besides, escapees can cause ecological effects through predation and increased competition for food. Insufficient maintenance, technical and operational failures are three important reasons for escapes to happen. Cages break down during storms, tear of the netting results in holes, and accidents during stocking, transferring and harvest can cause spill of fish.

Ongoing (2015) EU-funded research develops genetic markers for tracing the origin of farmed fish thus enabling to document genetic interactions between fish from aquaculture and their wild conspecifics (://aquatrace.eu/about-aquatrace). Such tools are needed to monitor to what extent farmed fish may actually harm wild populations.

Risks for escapes and associated impacts should be reduced by meticulous planning before establishment of an offshore farm and use of Best Available Technology. Escapes constitute economic loss to the aquaculture farmer and risks for loss probably are the best incentive for adopting risk management procedures and using the proper equipment scaled to the environmental forcings. Luckily, investments costs for sturdy equipment are rather modest (at 0.25-0.40 €/kg fish produced) if size of offshore farms exceeds 1,000 tons/y.

5.3.5 Pest transmission to wild stocks and to other farms

Transmission of pathogens between fish farms, from fish farms to wild stocks and from wild stocks to fish farms is a concern for fish farm producers, fishermen and for environmentalists. There are several mechanisms fostering such transmissions, including infected escapees acting as vectors, movement of infected wild fish between farm areas, pathogen germs being advected with currents from on farm area to another, and healthy-looking but infected fish transported from one farm to another by the producer.

Strict disease management procedures are required at all levels of the fish farming sector to prevent or minimize diseases and secure animal, human and environmental health. They include risk mitigation measures such as early treatment of infected fish, selecting productions sites with low hydrodynamic connectivity to other farms, minimize risks for escape incidents and through-out the production cycle improve operational routines. As in terrestrial meat production health management, preventive measures are the most effective and cost-efficient approach to maintain a healthy stock.

5.3.6 Fish farms attracting wild fish populations

Wild fish populations aggregate below and around fish farms with feed loss being the primary attractant. Wild fish aggregations consuming lost pellets and benthic fauna exploiting particulate waste potentially aid to ameliorate seabed effects by assimilating organic matter and dispersing nutrients over larger areas during migration. Wild fish such as cods that aggregate around salmon farms are in a better condition potentially improving fecundity and reproductive success (Dempster et al. 2011). Downsides and unknowns include higher infestations with ecto-parasites and altered composition of fatty acid compared with their wild counterparts (Dempster et al. 2009) that may affect egg quality or larvae survival (Fernandez-Jover et al. 2011).

In some areas fish farms have become targets for semi-commercial fishery functionally using fish farm areas as open traps. On the one hand catch and harvest of aggregated fish can be seen as a mean to recycle part of lost waste including nutrients, but on the other hand significant catch may counteract the potential stock enhancement function of the rich feeding grounds below cages. Obviously, additional research is needed to better understand ecosystem effects and to document the stock-enhancement potential.

5.4 Integrated Multi-trophic Aquaculture (IMTA)

IMTA refers to the concept of the co-culturing of different species for environmental and economic benefit. Usually, feed aquaculture species such as fish or shrimps are cultured alongside with species (e.g. mussels or seaweeds) who can take advantage of waste (uneaten feed, faeces and dissolved nutrients) released from the feed aquaculture production. Most IMTA projects have been implemented in land-based systems or in coastal systems with limited water exchange where residence time is long enough at allow lower trophic species to capture and assimilate waste from higher trophic species.

In offshore environments IMTA still is in its infancy and primary being tested in non-commercial RDI projects. IMTA options of cultured species coupled with fish cages include seaweed, bivalves, macro-algae or artificial reefs populated by a variety of fouling organisms. For IMTA to be successful there must be synchronisation between the growing cycles of the cultured species, but site environmental and hydrological conditions coupled with species life history cycles also play an important role.

The main challenge working against cost-effective implementation of “regular” IMTA in offshore environments is that the high rate of water exchange would tend to disperse and dilute dissolved nutrients and particulate waste to low levels making the capture and uptake in macro-algae and bivalves inefficient and the accompanying efficiency of waste reduction at a low level (Broch et al. 2013, Cranford et al. 2013, DFO 2013). As an alternative, capture of wild fish attracted to and feeding on waste or the stimulated benthic invertebrate community below cages can be a mean to “harvest” a (small) fraction of the waste.

In conclusion, traditional IMTA will be inefficient under offshore conditions because residence time in the water column will be too short for effective capture of waste by bivalves and by macroalgae. Instead, caged benthic high-value invertebrates (sea cucumbers, Abalone) established below fish cages or capture of wild fish feeding on particulate waste below cages can be an option, but cost-efficient holding at seabed and harvest systems need to be developed.

5.5 Case Study – comparison of environmental impacts of coastal and offshore fish farms

Competition for space, environmental constraints on carrying capacity in the coastal zone and negative public perception of coastal aquaculture are main drivers for moving fish cage farming to offshore sites. Intuitively, production at offshore locations could reduce environmental impacts, reduce risks of disease outbreaks and improve fish health and growth performance. However, there is very little information to back-up such claims. To this end, the Mermaid partner DHI carried out a model-based comparison of environmental impacts of two 5,000 tons (total 10,000 tons) rainbow trout growth out farms established at an offshore location in the Baltic Sea, i.e. at Kriegers Flak, (see D7.1 for further site-specific information) and at a nearby coastal site in Køge Bay.

Despite difference in depth (Kriegers Flak: 21-22m; Køge Bay: 14-15m) seabed characteristics were comparable; fine-medium sand at both sites; low benthic diversity with 4-12 species per 0.1 m^2 (gamma diversity ≈ 23 and 25 species; low biomass with 0.2-15 g ash free dry weight per m^2 and dominance of bivalves when occurring). Average salinity in Køge Bay was slightly higher at 8.2 ‰ S compared to 7.8 ‰ S at Kriegers Flak. Seasonal pycnoclines at 18-20m (Kriegers Flak) and 11-12m (Køge Bay) develop in calm periods during summer.

5.5.1 Models applied

Two set of models were used; large scale 3-dimensional models encompassing the Baltic Sea and providing Eastern boundary conditions to regional model of the Danish straits and a North Sea/Skagerrak/ Kattegat model providing Western/Northern boundaries for the regional model (Fig. 11). Except for spatial resolution the three models were identical. The 3D hydrodynamic MIKE3-FM model and associated ecosystem model developed in ECOLab were adapted to represent the specific ecosystem conditions in modelled areas. Models have been calibrated and validated against 10-40 years data. Specific attention was paid to fate of particulate waste from fish farms and how near-bed currents and wave action affected resuspension[4]. Resolution of the large scale models vary from 600m to 3 nm. while resolution of the regional model vary from 40 m (≈ dimension of a fish cage) in areas of specific interests to 1 km in the open part of the regional model area. Models simulate organic carbon and inorganic nutrients (NO_2, NO_3, NH_4, PO_4), total (N,P) nutrients in water column and sediment; iron-bound P and other “labile” P-species in sediment, dissolved oxygen, biological state variables (phyto- and zooplankton, macroalgae, seagrass) and detritus are described in terms of their C, N, P content. In addition, the models include an extended list of auxiliary (derived) variables including chlorophyll, light extinction coefficient, depth of oxic/reduced front in sediment.

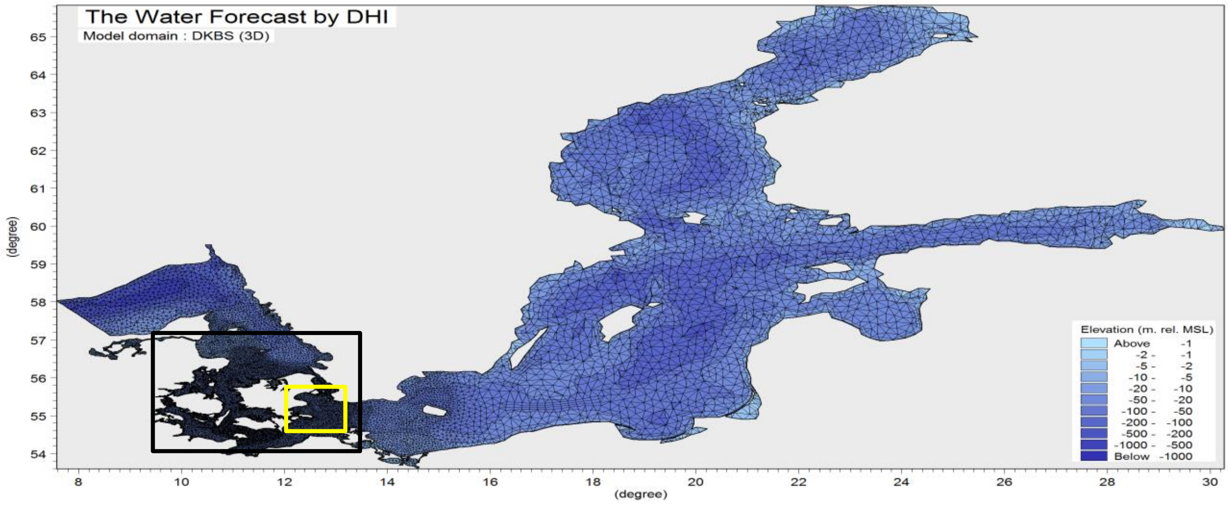

Figure 11 Modelled area; regional model is delineated by black rectangle and yellow rectangle show the area visualized in results section.

The regional model was executed for two years (2008 and 2009) and forced with boundary conditions, local meteorology, run-off and nutrient input (from land, atmospheric deposition and fish farm). Fish farm nutrient loadings were applied according to feed administration, stocking density and growth rate in Danish fish farms and, actual temperature in the two model years. A

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[4] Gross sedimentation (20 traps) below 2 fish farms (2,600 tons/y and 800 tons/y) was quantified in two fortnightly periods supplemented by statistical models relating current and wave shear stress to temporal variation (over 6 years) in excess C, N and P concentration in sediments below 8 fish farms

fallowing period (15 December – 31 March) was implemented in the fish farm model scenario. Model-run without fish farms represented baseline condition. Impacts of fish farm operation were estimated and visualized by subtracting modelled baseline data from fish farm scenarios.

5.5.2 Highlights of environmental impacts

Water column impacts

Nutrient enrichment in water column around fish farms differed majorly between the two sites; at the offshore site (Krigers Flak) the average excess total dissolved nitrogen ranged 1-2% in an area of 400 km^2 around fish farms, while the impact area (>1%) was 4 times larger around the coastal farms and the average nitrogen concentration within this impact zone was 6-7 times higher compared to the offshore farms (Fig. 12).

Concentration of chlorophyll was increased around fish farms; at the offshore site the average excess concentration did not exceed 2% of baseline conditions, while the coastal farms resulted in an increase in chlorophyll above 10% in the harbour channel of Copenhagen (Fig. 13). Moreover, the impact area (increase in chlorophyll > 1%) was at least 5 times larger than offshore impact.

The main reasons for stronger pelagic impacts of coastal fish farming are related to dilution and residence time of water. Strong currents through the Danish Straits (including the Sound) drive countercurrent circulation in Køge Bay leading to high residence time and low dilution rate. Besides, shallower depth at coastal sites inherently leads to lower dilution rates.

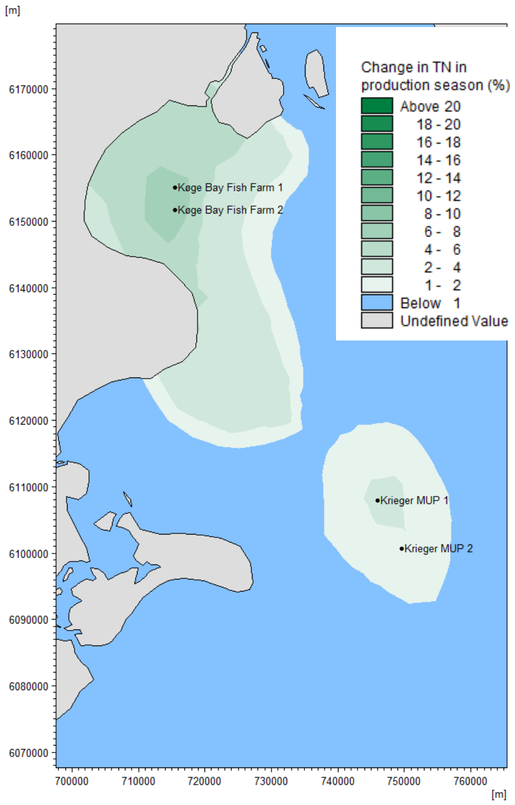

Figure 12 Increase in concentration (as % of baseline scenario) of total nitrogen in water column (0-10m) averaged during production season (1 April-15 December). Mermaid study by DHI.

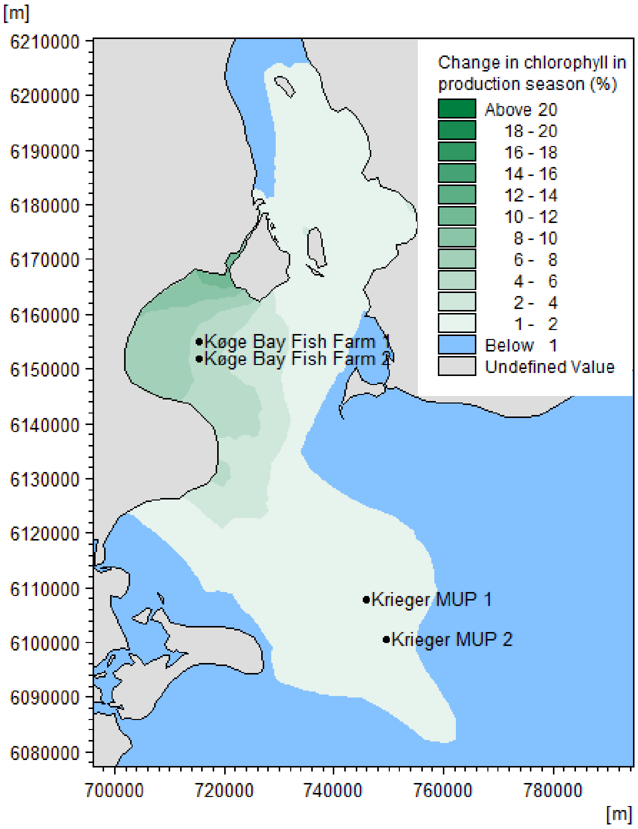

Figure 13 Increase in concentration (as % of baseline scenario) of chlorophyll in water column (0-10m) averaged during production season (1 April-15 December). Mermaid study by DHI.

Seabed impacts

Particulate waste and uneaten feed will sediment below fish farms and lead to increase in concentration of organic carbon, nitrogen and phosphorus on the seabed surface. Over time this waste will be incorporated into sediment, be degraded, be consumed by benthos and fish and be resuspended and advected to deeper and more calm areas. The predicted change in carbon and nutrient content in sediments differed between coastal and offshore fish farm sites. At the end of one years' production cycle (15 December 2008) sediment around fish farms at Kriegers Flak was enriched with carbon (1-2%) and nitrogen (1-4%) in an area up to 110 km^2 while impact area around the coastal farms was 4-6 times larger and impact levels up to 4 times larger
(i.e. 10-12% nitrogen excess) (Fig.14). At the end of the fallowing period excess carbon and nitrogen was still present at the coastal site but not at the offshore site (Fig. 15). Over years of repeated modelling carbon and nutrients gradually builds up at the coastal site but to a much lower extent at the offshore site.

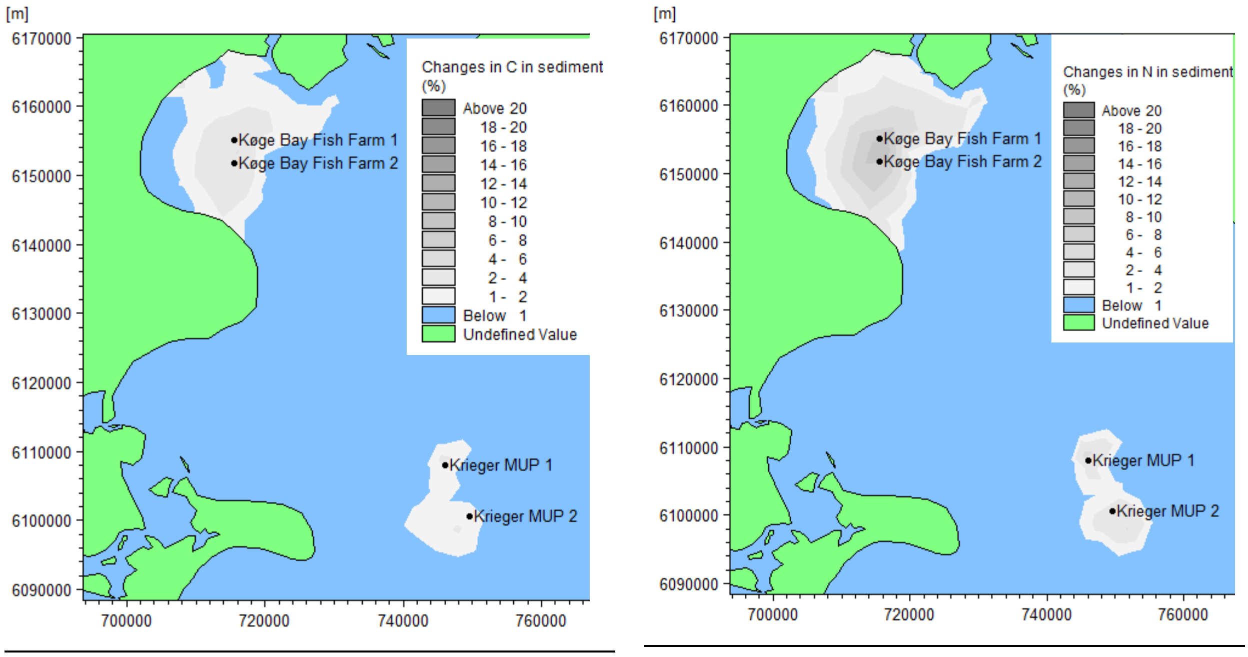

Figure 14 Increase in concentration (in % of baseline scenario) of carbon (left) and nitrogen (right) in in sediments at the end of first production period (i.e. 15th December). Mermaid study by DHI.

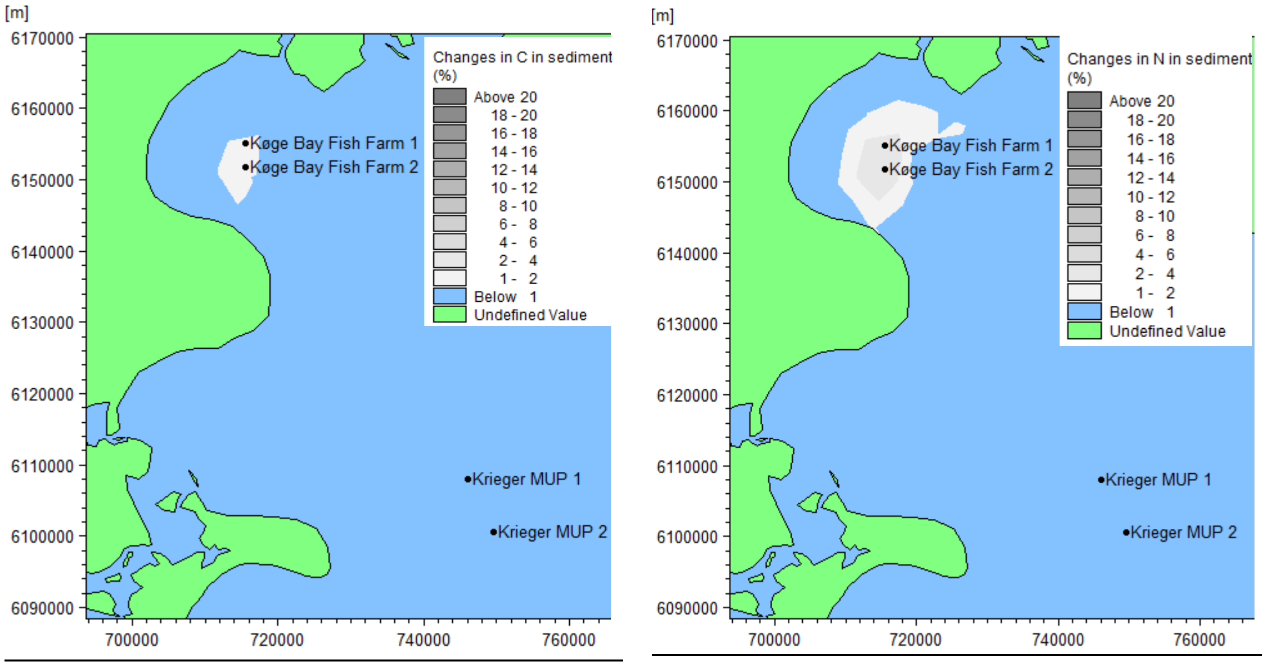

Figure 15 Increase in concentration (in % of baseline scenario) of carbon (left) and nitrogen (right) in sediments at the end of fallowing period (i.e. 31st March). Mermaid study by DHI.

In conclusion, based on numerical modelling of pelagic and benthic ecosystems it is very likely that fish farming carried at offshore locations will have much lower environmental impacts than fish farming carried out in coastal waters.

6 Impacts of Multi-Use-Platforms in off-coast environments

Multi-use-platforms is a concept that has not been realized yet and as such it is has not been proven if environmental impacts of combined use of marine renewable energy installations and aquaculture will be different from the sum of impacts of individual activities not sharing a confined area of the sea. Along with impacts on the environment positive or negative interactions between activities affecting the operation, maintenance and ultimately the profitability of activities also needs to be addressed.

Theoretically, environmental and operational benefits and drawbacks can be projected but without firm evidence from *in situ* studies such projections would be uncertain and influenced by background of the "specialist" making such projections. The content in following section should be viewed with that perspective.

Combining MREI and fish farms

Co-location of wind farms and fish farms is judged to be positive for both activities and for the environment.

There are several activities that are common for both sectors and available to cost-sharing. They include: 1) site-characterization needed in the site-selection process and for the EIA, 2) some operation and maintenance activities, harbour and vessel facilities can be shared. In case of very large fish farming (> 10,000 tons) hotel facilities on aquaculture feeding barges will be available for personnel maintaining wind farms.

Depending on MUP siting co-located fish farms and wind farms may promote wild fish stocks by providing "refuge" for fishery mortality in wind farms and access to great amounts of food below fish farm resulting in better conditions and probable higher fecundity.

The additional biofouling on wind farm structures stimulated by release a dissolved nutrients and particulate waste from fish farming may lead to increase in drag on structures bordering fish farm but will not affect efficiency of energy extraction.

Table 4 Overview of suggested wins (+) and loss (-) in operation and maintenance (O&M) for wind (wi), wave (wa) or tidal (ti) based energy extraction if co-located and coordinated with farming of fish (ff), mussels (mf) and seaweeds sf). Environmental wins (+), loss (-) or indifference (±) following co-location indicated.

	Fish farm		Mussel farm		Seaweed farm	
MREI	O&M	Environ	O&M	Environ	O&M	Environ
Wind	+wi /+ff	++	+wi /+mf	±	+wi /+sf	±
Wave	-wa /+ff	-	-wa /+mf	-	-wa /+sf	-
Tide	-ti /±ff	-	-ti /+mf	-	-ti /+sf	-

Co-location of wave or tide energy installations and fish farms is judged to be positive for fish farms caused by shadow effects resulting in milder wave climate provided by energy installations. In contrast, increased biofouling (and associated corrosion risks) on installations and moving structures by seaweed, mussels, and encrusting species may directly interfere with an efficient energy extraction. Biofouling can partly be controlled by treating structures with antifouling paint but that would increase maintenance costs and reduce operation time when the frequency of structures to be brought ashore, cleaned and re-treated with anti-fouling paint are increased. The environmental impact related to leachate of biocide is therefore judged to be slightly increased compared to separate operation of activities.

Co-location of wind farms and mussel or seaweed farms is judged to be slightly positive for both operations because of cost-sharing of activities as outlined above. The environmental impacts of co-located activities are not judged to differ from the sum of impacts of individual activities. Operation of mussel and seaweed farms is expected to benefit from co-operation with wave and tide energy extraction because of wave sheltering, while operation of wave and tide energy extraction activities probably will be less efficient because of increased biofouling (potential) released from mussel and seaweed farms. Changes in environmental impacts are expected to be very small but probably negative because of need for additional antifouling treatment.

Integration, coordination or co-location of aquaculture farms and marine renewable energy installations (e.g. wind farms) is on the hypothetical scale and predictions on benefits and drawbacks will be very uncertain. Solid predictions must await results from in situ scale experimentation.

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