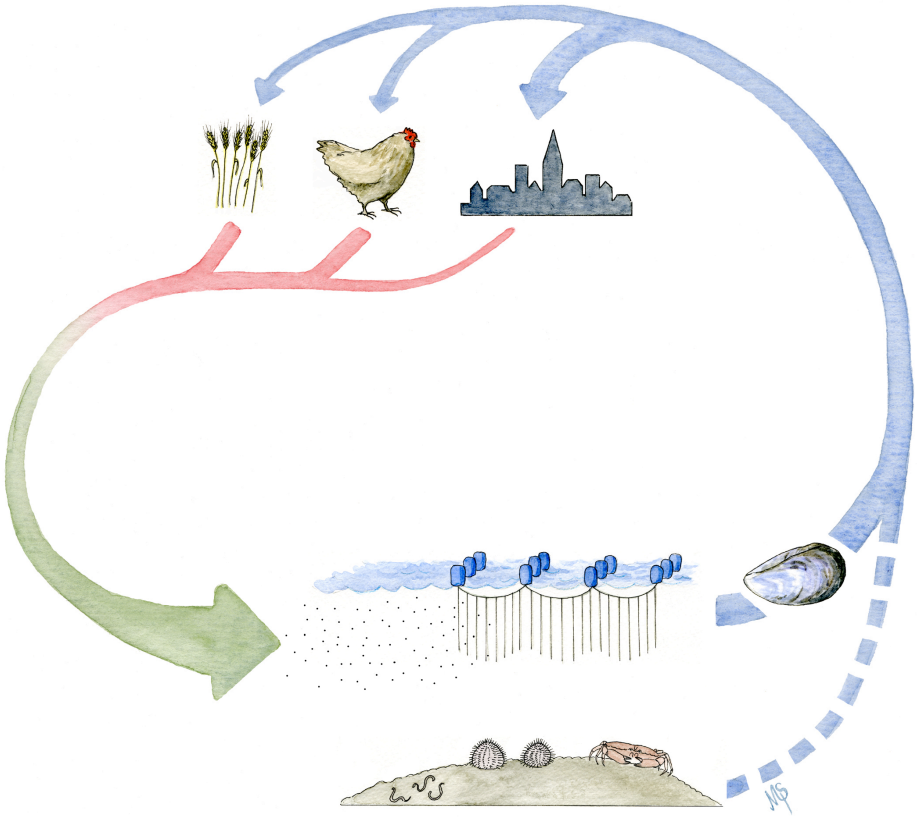
Production of Mussels – Mitigation and Feed for Husbandry (MUMIHUS)



The Danish Shellfish Centre
National Environmental Research Institute, Aarhus University
University of Southern Denmark
Technical University of Denmark
Bolding Burchard ApS
University of Copenhagen
New Zealand National Institute of Water and Atmospheric Research
Bedford Institute of Oceanography
University of Dalhousie

1. Summary

Increasing awareness of the need to change current production forms for food and non-food biological products, due to their environmental impact, challenges our perception of how nature is utilised. The need for natural products is increasing, and the utilisation of the goods and services provided by nature has to be managed in a sustainable way that ensures economic efficiency, and protects public and environment health. The concept of MUMIHUS is to bridge the gap between the need for new marine products and the need for measures that can mitigate eutrophication, which is the major threat to Danish coastal waters. This will be achieved through extraction culture of blue mussels, where excess nutrients in coastal waters are bound in the mussels and recycled into valuable products. Specific objectives are i) to adapt known techniques for optimal nutrient removal; ii) to assess environmental impact of blue mussel extraction culture; iii) to integrate the results in an ecosystem based management model in order to make an overall assessment of environmental impact; iv) to assess effects of low salinity and cyanobacteria occurrence on growth of blue mussels; v) to develop management tools for and economic analysis of extraction cultures as a mitigation measure; vii) to assess bioaccumulation of contaminants in blue mussels as a prerequisite for future use of mussels as feed in husbandry. MUMIHUS will include development of new techniques and products, blue mussel physiology and marine ecology using field studies, laboratory experiments and ecological and economic modelling. Anticipated results of MUMIHUS are scientific publications, a new long-line production method for extraction culture, a nutrient tradable permit system, ecological modelling of extraction culture and a potential source for a new feed additive to organic husbandry.

2. Objective of the project

The overall aim of MUMIHUS is to develop nutrient extraction cultures as a combination of biological production and a tool for mitigating effects of eutrophication in Danish coastal areas using blue mussels (*Mytilus edulis)* as culture organism. Specific objectives are i) to adapt known techniques for blue mussel production for optimal nutrient removal; ii) to assess environmental impact of blue mussel extraction culture on particle depletion and water column and sediment nutrient dynamics; iii) to integrate the results in an ecosystem based management model in order to make an overall assessment of environmental impact; iv) to assess effects of low salinity and cyanobacteria occurrence on growth of blue mussels; v) to develop management tools for and economic analysis of extraction cultures as a mitigation measure; vii) to assess bioaccumulation of contaminants in blue mussels as a prerequisite for future use of mussels as feed in husbandry. MUMIHUS will combine different scientific disciplines including marine biology and ecology, technical disciplines, dynamic modelling and socio-economic analyses. Extraction production of blue mussels has the potential to become an important management tool and can develop into a completely new line of businesses for production of important protein and lipid sources for organic husbandry or as a new product suitable for mussel spat export or as input to the existing mussel processing industry.

3. The main results of the project

The main results of MUMIHUS are the integration of natural and technical sciences with economic science in order to develop a new type of biological product in the coastal region and at the same time reduce the impact of excess loading of nutrients to coastal areas and contribute to strengthening the competitiveness of trade and industry. The experiences and approaches obtained within the project can therefore serve as a model for solving similar problems in the future, irrespective of the environmental issue at stake.

Specific expected results are cost-effective techniques for nutrient extraction cultures using blue mussels, tools for management of extraction cultures and economic assessment of extraction cultures as a mean of achieving environmental goals in relation to mitigation of nutrient enrichment of coastal waters. Furthermore, the results form the scientific and practical foundation for use of the extracted mussels, estimates of nutrient removal potential in extraction cultures, and new know-

ledge on integrated feedback mechanisms between extraction cultures and the environment. This foundation includes model assessment of the ecosystem potential of extractions cultures, and new knowledge on mussel growth under extreme conditions.

A number of additional results will also be included, e.g. estimation of nutrient dynamics in and around mussel cultures, particle depletion in micro-tidal environments characterised by high phytoplankton concentrations, resuspension rates of faecal material and effects of additional organic enrichment in already heavily enriched sediments. Likewise, an understanding of flow and turbulence structures around hanging culture units, which hitherto has been poorly understood, will be achieved, as well as scenarios of ecosystem impact of extractive cultures in relation to other efforts of mitigation and impact of salinity on optimal growth. Results on possible impact of cyanobacteria on mussel ingestion and growth, and assessment of possible concerns for hazardous substances in mussels and mussel meal is also included, as is at last, but not least, development of payment schemes for the environmental services and a tradable permit system for nutrients as well as a review of potential use of the cultured mussel.

4. Background and hypothesis of the project

Production of biological products in the coastal zone is challenged in several ways. Decades of nutrient load to Danish coastal systems (1) have in some ways made them very productive and thus suited for production. But in other respects, the nutrient load has had adverse effects like oxygen depletion events and has raised concern for ecosystem health. With the EU Water Framework Directive (WFD) this concern has been put into a management formula requiring actions to be taken by the responsible authorities (Danish municipalities) to reduce impact of nutrient emission and other disturbances in order to achieve good ecological status. We hypothesize that nutrient extraction cultures can be a part of the solution to the challenges of the WFD, since extraction cultures can provide new opportunities for removal of excess nutrients concomitant with production of food or non-food products. In addition, with extraction cultures it will be possible to mitigate in situ effects of nutrients leaking from the sediments. At the same time, valuable nutrients that are becoming rare (phosphorous) or are expensive to extract (nitrogen) can be recycled back to land as a valuable source of essential proteins and lipids. Hence, extraction cultures have the potential to be a cost-effective measure to reduce nutrient concentrations in coastal waters. It has been calculated (2) that marginal costs of nutrient removal by mussel farming can be considerably lower than other mitigation measures, but also that the cost-effectiveness depends on the mussel growth, the value of the mussels as well as on the nutrient load targets for a given area. It was also concluded that control costs from implementing this measure are considerably reduced.

The concept of extraction culture using blue mussels is currently being tested on the Swedish West coast, where it has been implemented as compensation for continued emission of nitrogen from the local sewage plant in a trial period from 2005-11 (3). The extraction culture in Sweden was, however, not designed for maximum extraction of nutrients and the blue mussels produced are intended for the fresh food market. Hence, production is dependent on market mechanisms and thus difficult to comply with environmental management. In addition, the Swedish project did not design a management system to control the efficiency of the measure and has not assessed the ecological impact of extracting nutrient through culture of organisms.

Using blue mussels as extractive organism has some implications, as blue mussel farming is known to modify the environment. Mussels capture particulate organic matter and transform it to tissue, released dissolved inorganic nutrients and easily decomposable faecal pellets that settle on the sediment surface (4). The benthic bio-deposits increase organic matter content and stimulate oxygen consumption and nutrient release (5, 6) as a function of production volume and the environmental conditions at the farming site (7). Increased benthic oxygen consumption under farms may increase the risk of hypoxia that already frequently occurs in Danish estuaries (1). In addition, nutrient release may further enhance the primary production in the vicinity of the farm and in connected areas, whereas the filtering capacity of the culture unit can improve the water quality

through removal of phytoplankton and clearing of the water column (8). The environmental effects of an extraction culture on basin scale depend on complex interactions between physics, biogeochemical processes and mussel feedback mechanisms. Because of this complexity, it is necessary to use a 3D ecological integrating model, including resolution of basin scale and local water flow, nutrient dynamics and ecological interactions as well as mussel physiology. Previous studies (e.g. 9, 10) have mainly focused on estimating the production carrying capacity of mussels whereas the positive and negative feedback of blue mussel farming on the environment have been neglected and local flow patterns have not been considered. The environmental interactions of extraction cultures can be designed to deviate from the traditional long-line farming by focussing the production on the initial exponential growth phase.

For extraction cultures to be a national tool in Denmark, it is important to take into account restrictions on growth by natural conditions. Salinity impacts mussel growth (11), reproduction (12) and formation of byssus for attachment (13). Increasing food access by production in the surface may optimize food conditions and counteract some of the reduced growth observed in mussels at low salinity. Cyanobacteria blooms are a characteristic, natural feature of brackish waters (14) and in recent years blooms have increased and will likely continue to do so, due to global warming (14). Cyanobacteria may impact mussel growth, primarily by being a poor food source lacking essential polyunsaturated fatty acids (15) and being difficult to ingest and digest. Little is, however, known about cyanobacteria and growth of blue mussels.

Following the principles in (16) extraction culturists can be provided with incentives for optimal mussel production by pricing the provision of the external good, i.e. the non-marketed nutrient removal service, which is an external benefit to society, either by an introduction of governmental payments for the provision of the environmental services, or through an introduction of a tradable permit market between the providers of the environmental service (the compensation mussel farmer) and the polluters. Extraction culture is ideal for this purpose as the environmental service in this case is an observable commodity, which is not always the case for environmental services. A way of creating the right prices is to create markets and trade between polluters and environmental service providers, e.g. through a tradable emission quota system (3). US EPA has made guidelines for effluent trading, including recommendations for obtaining credibility and success by establishing e.g. clear mechanisms and legal authorities, but despite these guidelines uncertainty elements for obtaining successful markets have to be analysed. Uncertainty elements are e.g. provision, actual nutrient removal and mussel productivity, as well as if it is possible to establish effective markets (attract willing buyers and sellers). Solving these uncertainties also involves investments in institutions to handle the market trading.

The cultured blue mussels can be used for several purposes, depending on their concentration of hazardous substances. Native blue mussels in Danish waters are known to contain low amounts of metals and organic contaminants (17). Furthermore, the use of pelagic mussel farms is hypothesized to reduce the uptake of hazardous compounds, as they are not in contact with the usually more contaminated sediments. Even so, bio-concentration from the water to mussels is in several orders of magnitude, and concentrations in end products like mussel meal may exceed acceptable levels for commercial use.

5. Innovative value, impact and relevance

The main innovative aspect of the MUMIHUS project is its holistic approach combining the production of a healthy source of proteins and essential lipids with mitigation of anthropogenic stress, in this case nutrients, in a new and innovative way. The simplistic beauty in using nature itself for self-healing, challenges today's focus on high-technological approaches to solve environmental problems. It also provides alternatives or supplements in a transitional phase to cost inefficient or political difficult reductions in e.g. agricultural practice. By growing mussels, a vital product is generated and essential nutrients are recycled, which can save considerable energy costs by avoiding production from conventional sources.

Production of food and non-food biological products is challenged by increased demands for sustainability and especially in the coastal zone will implementation of the EU WFD impose limitations on biological production. The concept of MUMIHUS is to change the unidirectional flow of mineral nutrients from land to sea to a return flow by bringing back nutrients from sea to land in the form of nutrients bound in mussels and by regarding the emitted nutrients as a resource that can be recycled. Hence, biological production can be combined with the necessary nutrient extraction from coastal waters and thereby add to the mitigation of decades of excessive human-induced inputs of nitrogen and phosphorous that have become the main threat for water quality. Use of blue mussels for production of meal can be an important protein source in organic feed for poultry and pigs and will make it possible to replace a vanishing resource, i.e. fishmeal. Alternatively, the mussels can be used for other purposes with commercial or societal potential.

MUMIHUS addresses the keywords for Theme 3 as it develops a new non-food market and combines it with not just a sustainable production form but also with actual mitigation of anthropogenic stress. The impact is a new way of thinking with regard to use of natural resources, turning potentially environmental threats into assets to society. Especially, MUMIHUS will change the normal view of essential mineral nutrients like nitrogen and phosphorous as waste products from agricultural production into seeing them for what they are - valuable and increasingly vanishing resources that can be recycled. Further, MUMIHUS will introduce the concept of tradable permits in mitigation of eutrophication.

6. Project methodology and results

The core activity in MUMIHUS is the establishment of a full-scale mussel farm given by the standard size (250 x 750 m) set by the Danish Directorate of Fisheries for long-line units. The long-line unit will be a platform for tests of production technology, environmental impact of extraction culture and calculation of costs associated with extraction culture and is situated in the Skive Fjord. MUMIHUS will rent an established long-line unit equipped with 90 long-lines from April 2010 to May 2011.

WP1 is assigned to tests of different production technologies. The key element will be achievement of maximum yield for a minimum of handling costs, i.e. no intermediate treatment, and different settling media will be tested. Continuous loops will be used on the lines and experiments with distance between loops as well as harvest time (Dec. 2010, Mar. & May 2011) will be carried out. The purpose of these tests is to find the optimal system for harvesting maximal mussel biomass using lowest labour investment. Finally, Skive Fjord is frequently subjected to severe oxygen depletion and experiments with different types of suspension depth will be carried out. Biometric mussel data (density, length, dry weight, gonad dry weight) and loss of mussels to the bottom will be measured approx. 20 times during the production period. Removed N & P will be calculated from measurements of biomass and nutrients content in collected animals. Costs of removal of nutrients will be calculated based on the actual production costs including materials, labour costs and depreciation of establishment costs and boats. The long-line unit is established, arrangements for hire of a harvest boat have been made and the DSC technical staffs is experienced in mussel farming. Hence, risks associated with this key activity are considered as small. As alternatives, there is in the Limfjorden other long-line units and harvest boats that can be hired.

WP2 is dedicated to measurements of effects of extraction culture on different scales and for a number of different parameters. Measurements will be performed on a regular basis during the production period and in designated campaign periods. A monitoring programme consisting of weekly or bi-weekly sampling of dissolved and particulate nutrients, particulate matter, detritus, chlorophyll a (size fractionated <0.2 and >3 μm), oxygen, salinity, temperature and zooplankton biomass will be established for Skive Fjord in relation to the culture unit. In addition, 2 Aanderaa loggers (salt, temperature, current speed and direction) will be moored for the entire period at the entrance to the modelling area. During campaign periods, different types of measurements will be carried out. One set of measurements will consist of the determination of flow and turbulence struc-

tures around hanging units combined with measurements of phytoplankton depletion utilizing a rapid 3-D mapping approach. ADCP and CTD will be used for measurements of flow and density structure, and ADV and SCAMP (Self Contained Autonomous Micro Profiler) for fine-scale turbulence. The spatial resolution of particle removal at the farm level will be investigated by the use of a computer-controlled undulating vehicle (Acrobat LTV-50, SeaScience) during 2-3 field campaigns (10). In addition, particle depletion on the micro-scale will be measured using siphon mimics (18) and in enclosures. Another set of experiments will be in situ studies of nutrient and oxygen dynamics on long-lines in order to explore the realized fluxes at farm level. Short lines (1 m) with settled mussels (and epibionts) will be incubated in closed mesocosms with simulated mixing and natural particle concentrations and continuous measurements of oxygen by optodes (19). Water samples will be taken from the enclosures and from open lines using siphon mimics and analysed for nutrients. Spatial and temporal variations in fluxes will be examined by several incubations in the farm and several times over the production cycle. In addition, excretion rates of individual mussels will be assessed through experimental studies in the laboratory on mussels collected, whereas clearance rates will be obtained from the literature. Finally, impact on and recycling from the sediment will be studied. Sediment organic matter pool and oxygen and nutrient dynamics will be examined by seasonal sampling of sediment cores by scuba diver under the culturing unit. Sedimentation of biodeposits will be examined during sampling of sediments by deployment of sediment traps and counting of faecal pellets and measuring total sedimentation. Sediments will be incubated in the laboratory for fluxes of oxygen and nutrients and finally sectioned to obtain organic matter and nutrient content using standard methodology. Sulphide, Eh and organic content in sediments and a quantification of mussel debris under the farm will be investigated during campaigns. Resuspension will be measured using a moored turbidity sensor during campaign periods. Trophic interactions in the benthic fauna will be explored by the use of stable C and N isotopes according to (20). This will allow for an assessment of possible benthic impact on the faunal community.

WP3 concerns the environmental effects of mussel compensation cultures on basin and farm scale. This will be studied using a 3D integrated modelling system including descriptions of hydrodynamics, pelagic- and benthic biogeochemistry and mussel population dynamics and energetic. The General Estuarine Transport Model (GETM) will describe stratification, mixing and advection processes on a horizontal resolution of 50×50 m. Boundary conditions are obtained from the monitoring in WP2 and the Miljøcenter in Aalborg will provide data on surface elevations. The GETM model was previously applied to the Limfjorden in the EU-financed project Managing Benthic Ecosystems in relation to Physical Forcing and Environmental Constraints (MaBenE). The biogeochemical model is a modified version of the MPD (microplankton-detritus) model (e.g. 21) that describes the cycling of C, N and P through microplankton and detrital compartments and includes a dynamic coupling of pelagic and benthic processes. The model will be improved by better descriptions of bio-deposition and benthic fluxes of nutrients- and oxygen beneath and outside a farming unit based on new evidence obtained in WP2. Specifically, we will parameterise a simulation model of sediment resuspension, which includes changes in erosion thresholds due to bio-film, biodeposits, and grain size, as well as the settling characteristics of these particles. Boundary layer flow will come from GETM. The eco-physiological response of mussels to a changing environment is described by a Dynamic Energy Budget (DEB) model and coupled to a population model describing recruitment and mortality of individuals within a cohort. The mussel model will be improved by new estimates of filtration, ingestion and growth rates at varying salinities and phytoplankton compositions (cyanobacteria) from WP4. In addition, a farm-scale model with a horizontal resolution of 3×3 m will be imbedded in the local 3D model. The farm-scale model will describe the local hydrodynamics and biogeochemical fluxes around and within a farming unit. The model is calibrated against detailed field measurements of small-scale hydrodynamics, depletion of phytoplankton and nutrients- and oxygen fluxes estimated in WP2. The integrated model system will be validated against measurement obtained in the monitoring program NOVANA and in WP1+2. Model scenarios will be conducted in order to estimate the impact of mussel compensation cultures on oxygen

conditions, Chl a concentrations, Secchi depth and N and P cycling in the ecosystem and removal of nutrients through harvesting of mussels. The optimal location, number and size of farm units and distance between them and the time needed before the environmental improvements are detectable will also be tested using the model system.

WP4 investigates the potential for production of biomass of blue mussels for industrial use at 5 sites in relation to salinity and food conditions (eutrophication). The sites will include open and more sheltered areas, such as low saline fjords. At each site a test production will be established from May to October in two years. The production will be analysed as a function of timing of spat collection, salinity and food conditions. Filtration as a function of salinity will be investigated in field and laboratory experiments. The byssus attachment will be tested in laboratory experiments and in the field on long lines as a function of salinity. To examine the growth potential of blue mussels in the naturally occurring range of salinities in Danish fjords, a test kit will be developed in WP4, where newly settled mussels on lines will be deployed at several test locations. The growth of mussels will be quantified by weight and length, and the potential food sources through stable isotopic signals (C and N, 20). The impact of cyanobacteria concentration and aggregate formation on growth rate, clearance rate, and pseudofaeces production of newly settled and adult blue mussels will be investigated in situ and in laboratory experiments. Possible additive effects of cyanobacteria concentration in combination with low salinity will also be investigated. In a campaign period filtration (using defecation rate and gap size methodology) and individual and population growth (shell length, DW) will be investigated at test sites. In laboratory experiments, the filtration of different particle concentrations of different cyanobacteria and salinities (constant 5-10-25 PSU and fluctuating salinities) will be conducted. The filtration will be measured as clearance, and the filtration and the behaviour mussels will be analysed by video (gap size, pseudofaeces production, clogging response) to test if cyanobacteria concentration induces a changed response. The individual growth will be measured. During the experiment faeces and pseudofaeces will be sampled and the indigestion of the different diets will be examined.

In WP5 the economic assessments of extraction culture will be directed to 1) analysis of the cost-effectiveness of extraction culture mussel production compared to other nutrient abatement measures in agriculture and point sources, and 2) analysis of efficient use of market based incentives for extraction culture production different from conventional mussel production. Two types of incentives are considered, a): use of payments for environmental services (PES) and b) quota trading between farmers and mussel producers. In 1) the cost-effectiveness of mussel production as compared to other nutrient abatement measures are modelled by introducing mussel production and nutrient abatement effects in a cost-minimisation model for the Skive fjord, built on the cost-minimisation model for the Baltic Sea (22) and Odense river basin (23). In 2) the incentives to produce mussels and provide nutrient abatement by environmental payments to mussel producers are assessed estimating social efficient provision of nutrient abatement by mussel production by designing a principal-agent model for the government/local authorities and the mussel farmers (24). The results from this analysis will be payment schemes with the potential to work as effective incentives for the mussel producers, paid by the government. The other economic incentive to be analysed is a system of quota trading between farmers and extraction culture producers. Quota trading is analysed by estimating the farmers' marginal profit subject to the nutrient emission from the farms using programming models for farms in the drainage basin to Skive fjord (23). The results from this analysis is shadow prices of how much it is optimal for the farmer to pay the mussel producers for nutrient abatement by buying emission permits. Such quota systems are also modelled for fisheries (25). The willingness of the farmers to pay for the nutrient permits is dependent on the costs of the permits relative to the costs of other measures to decrease the nutrient emissions.

In WP6 different uses of the extraction cultured mussels will be investigated. The main activity will be directed towards the potential use of the mussels as feed for poultry and pigs. To examine any bio-magnification of toxic substances in the mussels, experiments will carried out. Free metal concentration in the water column (passive metal samplers and spot sampling) will be

measured at a number of sites (including the study site) with different salinity (in relation to WP4) and combined with measurements in suspended material as input to a kinetic model for uptake in mussels (2). In combination with the metal passive samplers, a silicone sheet passive sampler with Performance reference compounds will be used to assess the sampling rate, combined with the current measurements from the other work packages. To assess the dietary quality and removed amounts of N, P, the final product is ground to a feed in two forms, with and without the shells, and duplicate samples are analysed for metals, methyl mercury, C, N, P and dioxin and furans of these finished products. Analysis will be performed using accredited methods for mussel and suspended matter (ICP-MS, GFAAS and CV-AFS) for the metals and P. C and N will be analysed using an automated CHN-analyser. Dioxins will be analysed using high-resolution GC-MS. Potential alternatives to use of the mussels as feed are: 1) input to the industry (frozen or canned mussels); 2) export as seed to e.g. the Dutch on-bottom mussel farming industry; or 3) an energy source for biogas production. The alternatives will be assessed through theoretical studies and interviews with key personnel in Denmark and Holland.

A platform will be constructed for measurements in WP2, the partners are familiar with the applied methods and technology and there is an existing platform for the modelling efforts. Even though the perspectives are new, methodology is known and alternatives exist, hence risks are considered to be low.

7. Project plan

The timetable for the MUMIHUS work packages is shown in Table 1 and the milestones are described in Table 2.

WP	2010	2011	2012	13	Partner
WP1.1					DSC
WP1.2					DSC
WP1.3					DSC
WP1.4					DSC
WP1.5					DSC
WP1.6					DSC
WP1.7					DSC
WP2.1					DSC
WP2.2					DSC
WP2.3					NIWA
WP2.4					BIO
WP2.5					UDal
WP2.6					SDU-BI
WP2.7					SDU-BI
WP2.8					SDU-BI
WP3.1					BB
WP3.2					BB
WP3.3					MAR
WP3.4					MAR
WP3.5					MAR
WP3.6					MAR
WP4.1					SDU-BI
WP4.2					DSC
WP4.3					DTU
WP4.4					DTU
WP4.5					DTU
WP5.1					SYS
WP5.2					KU-FOI

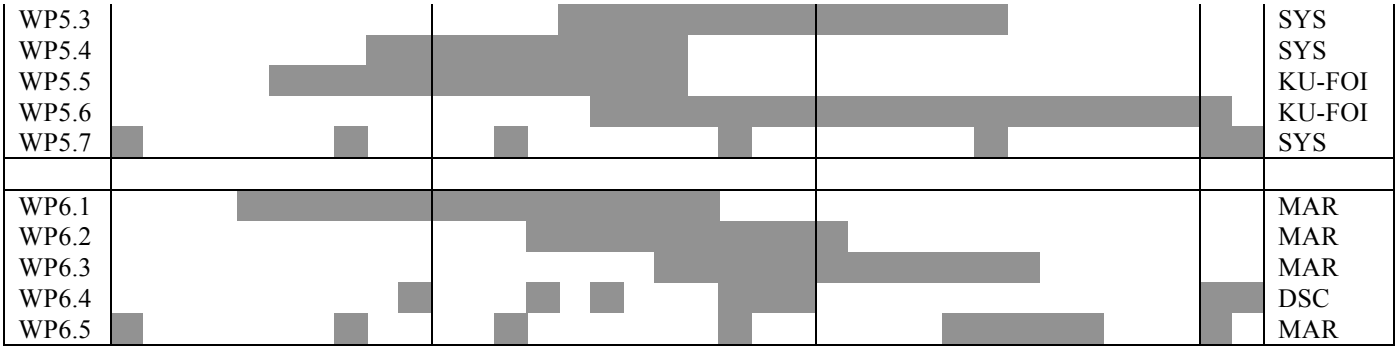


Table 1. Distribution of work during the project period and divided by work packages. Partners responsible for the work and milestones are indicated for each work package. Milestones are indicated as the end of each shaded block.

Milestone	**WP**	**Description**	**Person months**
1	1.1	Test unit established and spat collectors mounted	5
2	1.2	Management of extraction cultures	8
3	1.3	Monitoring programme designed	4
4	1.4	First harvest	1
5	1.5	Second harvest	1
6	1.6	Third harvest	1
7	1.7	Reporting, publishing and meetings	4
8	2.1	Coordination of field campaigns	1
9	2.2	Monitoring programme carried out	10.4
10	2.3	Flow and turbulence structures around hanging units	0.6
11	2.4	Phytoplankton depletion around hanging units	1.8
12	2.5	Estimation of resuspension rates of POM	2
13	2.6	Spatial and temporal variability in benthic interactions in extraction cultures	12
14	2.7	Trophic interactions in extraction cultures through mussels, attached fauna and benthic fauna	9
7	2.8	Reporting, publishing and meetings	3
15	3.1	Local hydrodynamic model of Skive Fjord	9
16	3.2	Farm model	7.5
17	3.3	Improved Dynamic Energy Budget model of blue mussels	3
18	3.4	Local ecological model of Skive Fjord	10
19	3.5	Scenario testing	10
7	3.6	Reporting, publishing and meetings	3
20	4.1	Nutrient retention in mussels assessed by stable isotope signals	6
21	4.2	Experimental design	1.4
22	4.3	Field experiment on mussel production as function of salinity and food composition	22.5
23	4.4	Lab experiment on filtration and growth as function of salinity, food composition	22.5
7	4.5	Reporting, publishing and meetings	3

24	5.1	Cost-minimization model for Skive fjord including costs and nutrient removal by mussel production, run scenarios	2
25	5.2	Analysis of uncertainties related to the provision of environmental services from mussel production	2
26	5.3	Establish principal-agent model for analysis of Payment schemes for the environmental services, including uncertainties	2
27	5.4	Run empirical model for payment schemes on data from mussel producers and 5.1.	2
28	5.5	Theoretical model for tradable permits described	2
29	5.6	Permits markets analysed empirically	4
7	5.7	Reporting, publishing and meetings	3
30	6.1	Spatial and temporal variability in heavy metals in the water column and extraction cultures	2
31	6.2	Variation in contaminants in mussel meal dependent on harvesting occasion	1
32	6.3	Kinetic model for heavy metal uptake in mussels	1
33	6.4	Evaluation of use of cultured mussels	1
7	6.5	Reporting, publishing and meetings	1
All		Project management	7.3

Table 2. List of milestones for MUMIHUS with an indication of resource allocation (person month) for each milestone.

8. Projects international dimension

Two international partners are directly involved in the project. Dr. C. Stevens and his associates from the New Zealand National Institute of Water and Atmospheric Research have as some of few in the world studied and modelled flow patterns around culture units. Dr. Stevens will bring equipment, expertise and experience within measurement of flow structures around culture units that are essential for the modelling of particle depletion. Dr. P. Cranford from the Bedford Institute of Oceanography in Canada has extensive national and international experience with research in different aspects of mussel production, but with focus on carrying capacity. Dr. Cranford will bring expertise and equipment that are essential for measuring particle depletion. Dr. J. Grant from Dalhousie University in Canada has extensive experience from national and international projects with modelling mussel carrying capacity. Dr. Grant will bring important modelling experience to the project and specifically contribute with measuring and modelling of effects of resuspension.

Other international activities will be participation in Aqua-DEB and international conferences. Aqua-DEB is a European network for the development of dynamic energy budget modelling of shellfish. NERI is associated the network, but will with MUMIHUS be able to participate more directly in the network. A number of international conferences are specifically targeted issues relevant for MUMIHUS like the symposia of the European Aquaculture Associations Euroshell sessions and the international Shellfish Restoration Conference, but in a number other conferences and meetings will there also be relevant sessions. Finally, several of the MUMIHUS partners are actively involved in shellfish networks on a European scale and will with MUMIHUS have an opportunity to promote Danish shellfish research.

9. Legal and ethical aspects, etc

MUMIHUS will use an existing mussel culture unit as platform for the experiments. The unit will be hired from Dansk Linemusling a/s that has a production permit from the Danish Directorate for Fisheries for the unit under the license number 112. Permanent mooring of Aanderaa current meters

during the one year monitoring period will require a permit from the Danish Maritime Safety Administration, which is normally granted. Starting MUMIHUS 01-01-2010 is due time to apply for the permit to be in operation 01-04-2010. For all operations within the culture, no further permits are required as a culture unit is restricted area and only for use by the licensed holder of the production permit. Dansk Linemusling a/s has made an agreement with the MUMIHUS consortium for use of the culture unit for the period 04-2010 to 05-2011.

No ethical aspects have to be considered in the project.

10. Publication and promotional strategy

The broad and international MUMIHUS partnership will secure a large platform for dissemination of the results of MUMIHUS in an efficient way. Scientific dissemination through relevant and high-quality peer-reviewed journals and scientific meetings is the responsibility of the WP leaders and will be discussed at Steering Committee meetings, in particular for the expected multidisciplinary publications bridging more than one WP. Estimated approx. 15 publications in peer-review journals are expected as an outcome of MUMIHUS. Dissemination of the results to the society at large and in the Limfjorden region in particular will take place through a seminar arranged in the third year of the project for targeted groups (national and regional environmental protection agencies, policy-makers, other stakeholders). Furthermore, MUMIHUS partners will participate in upcoming events and media opportunities in the region and MUMIHUS will provide a dedicated public web page for dissemination of the results to the public as well as the targeted groups described above. Finally, DSC expects to open an information centre on the ecology of the Limfjorden and biological, environmental and technological aspects of shellfish production. This centre will be used for dissemination to the public. As DSC is currently hosting a network for the Danish mussel industry and research institution, this forum will be used as platform for targeted dissemination to this segment. Dissemination of results will be a continuous process from the start of the project, and all partners will contribute to the dissemination of the findings. The study-site activities will provide many opportunities for direct interaction with the policy-making process and stakeholders at local and regional levels, and several stakeholders have already showed interest in the activities in the Limfjorden, e.g. Limfjordsrådet.

11. Exploitation of results

Expected results of MUMIHUS to be immediately exploited by society fall in four categories: a) Technological improvements of mussel production; b) evaluation of extraction cultures as a measure for mitigation of anthropogenic stress, i.e. nutrient loading of costal waters; c) management tools for extraction cultures; and d) screening of possible use of extraction culture mussels.

The technological improvements obtained in MUMIHUS will have implications not only in an extraction culture context but also for conventional mussel farming and will contribute to cost-benefit analysis of different production methodology. DSC is as part of its statuary obliged to promote the Danish mussel industry and will use the industrial network to disseminate results to mussel farmers. In addition, MUMIHUS will use the production facilities of Dansk Linemusling and will thus have a direct counterpart for exploitation of technological achievements. Similarly, will results of the evaluation of possible use of the produced mussel be made available to the industry and are expected to be directly exploitable.

The overall evaluation of extraction cultures as a tool in combating effects of excess nutrient loading in coastal waters will have local, regional and national environmental management authorities as primary end-users. Both NERI and DTU-Aqua have obligations to respectively the Ministry of Environment and the Ministry of Food, Agriculture and Fisheries and serve as advisory institutions. Both parties are also involved in the Baltic Nest Institute, which host the Nest model, a decision support system aimed at facilitating adaptive management of environmental concern in the Baltic Sea. With the formation of an advisory board (see below) additional ways of communicating the main results to responsible authorities will be established. The results of MUMIHUS may thus

reach the potential end-users rapidly and since the main purpose of the project is to develop a new tool for combining biological production with mitigation of eutrophication, a success criterion is exploitation of the project results.

All model building will be published under GNU Public license and is thus open source. Issues of intellectual property rights will only be relevant in relation to publication in peer-reviewed journals and the private companies involved in MUMIHUS will not claim exclusive rights for exploitation of results.

12. The participating parties

The MUMIHUS partnership consists of:

- **DSC** (The Danish Shellfish Centre) is a SME with the aim of developing the Danish shellfish business through research and development activities. DSC has 10-12 employees. DSC has participated and coordinated several national projects on shellfish production and is currently participating in 2 EU projects. PI J. K. Petersen (JKP) is director of DSC, has coordinated 1 EU and several national projects and is member of the Danish Mussel Committee. JKP has extensive management experience as head of section in NERI-MAR and currently as managing director. JKP will perform the scientific coordination of MUMIHUS and participate in the steering committee. DSC will lead the project and WP1, be responsible for the technological development of the extraction culture and sampling for WP2 and WP6 and will host experiments in WP4.
- **NERI-MAR** (National Environmental Research Institute, Aarhus University, Dept. of Marine Ecology) performs applied research in marine ecology. NERI-MAR is in charge of the Danish national environmental marine monitoring. DMU-MAR has participated and led several national and EU projects. PI I. Dahllöf (IND) has extensive experience on eco-toxicology and harmful substances and will lead WP6. IND has management experience as coordinator of several projects and has been head of section at NERI-MAR. PI M. Maar (MAM) has been working with mussel and ecological modelling for several years, is associated Aqua-DEB, is co-coordinating an existing DSF-project and will lead WP3. NERI-MAR will be responsible for the modelling and the output evaluation and will perform analysis of samples collected in WP1 and WP2. NERI-MAR will manage the project and MAM will participate in the steering committee.
- **NERI-SYS** (National Environmental Research Institute, Aarhus University, Dept. of Policy Analysis) develops and communicates knowledge about interactions at the society-environment interface. PI B. Hasler (BH) is experienced in research involving integration of knowledge, data and models from social and natural science, and is experienced in economic, environmental and political scientific disciplines. BH has extensive management experience from projects and is currently head of section in NERI-SYS. NERI-SYS will lead WP5, develop a management model and a tradable permit system for nutrients. BH will participate in the steering committee.
- **SDU-BI** (University of Southern Denmark, Inst. of Biology) covers subjects in biology with focus on aquatic biology, including marine ecology. PI M. Holmer (MH) has research experience in effects of aquaculture on the marine environment and project leader experience from several EU, international and national projects. The EU projects have involved aquaculture with particular focus on the environmental issues. SDU-BI will lead WP2 and be responsible for studies of nutrient cycling, benthic impact and trophic interactions. MH will supervise the post doc.
- **DTU-Aqua** (Technical University of Denmark, Institute of Aquatic Resources) performs fisheries and aquaculture research, including production of mussels. DTU-Aqua has participated in several national and EU projects on mussel production. PI P. Dolmer (PDO) has many years of experience with studies and assessment of mussels, has been lead on several national projects. PDO has management experience from many projects and is currently head of section at DTU-Aqua. DTU-Aqua will lead WP4 and will conduct all experiments with mussel tolerance to adverse conditions. PDO will supervise the PhD-student and participate in the steering committee.
- **BB** (Bolding Burchard ApS) is a SME devoted to the development and application of advanced numerical ocean models. The partners in BB – K. Bolding (KB) and prof. H. Burchard (HB) -

have more than 25 years of experience in oceanography with specific expertise in 3D hydrodynamic modelling, turbulence, mixing, coupled ocean-atmosphere dynamics, data assimilation and computer science. BB is maintaining the two modelling projects GETM (www.getm.eu) and GOTM (www.gotm.net). BB will participate in WP3 and develop the hydrodynamic module on both basin and farm scale.

- **KU-FOI** (University of Copenhagen, Institute of Food and Resource Economics) conducts research in the area of food and natural resources embracing theoretical and applied economics, bio-ethics and law. PI H. Frost (HF) has extensive experience in environmental economics with particular reference to fisheries economics. KU-FOI will participate in WP5 and will be responsible for economic analysis of extraction culture and participate in the economic modelling of a property system.
- **NIWA** (New Zealand National Institute of Water and Atmospheric Research) is a Crown owned research and consultancy company covering water and atmospheric research and with extensive experience in various aspects of mussel production and aquaculture. PI C. Stevens is trained oceanographer with experience in measurements and modelling of flow around canopies including mussel farms. NIWA will participate in WP2 and WP3 and be responsible for measurements of flow in and around the culture unit and will contribute to the modelling of physical structures on farm scale.
- **BIO** (Bedford Institute of Oceanography) is the largest centre for ocean research in Canada and performs targeted research to provide advice and support to government decision making on a broad range of ocean issues, including the sustainable use of natural resources. PI P. Cranford (PC) has extensive experience with mussel carrying capacity studies and has participated in numerous national and international projects. BIO will participate in WP2 during campaign periods and PC will be responsible for studies of chlorophyll depletion and micro phytoplankton dominance.
- **UDal** (University of Dalhousie, Canada) UDal is the premiere research university in eastern Canada. The Department of Oceanography is among the most highly regarded worldwide. Jon Grant's (JG) lab has been involved in studies of aquaculture and the environment for 20 years. Specializing in field and modelling studies of mussel culture, they have pioneered the definition and characterization of carrying capacity in coastal waters. As an expert in particle dynamics, JG will interact extensively in WP2 and WP3 by quantifying resuspension relative to the role of mussels.

13. Project management

MUMIHUS is hierarchically organised with work packages as the basic unit. Work packages are the forum for the daily work in MUMIHUS and include (lead partner in bold):

1. Extraction culture: Optimization and technological improvement of mussel farming to maximize yield. Partnership: **DSC**.
2. Environmental impact: Sampling of data end measurements of nutrient cycling, particle depletion, flow structures on farm scale, sedimentation/resuspension and trophic interactions Partnership: **SDU**, DSC, NIWA, BIO, UDal.
3. Modelling: Coupled 3D hydrodynamic, ecological and blue mussel physiological model for the Skive Fjord and the extraction culture unit. Partnership: **NERI-MAR**, BB, UDal, NIWA.
4. Growth limitations: Clearance, ingestion, pseudofeces production and growth at low salinity and occurrence of cyanobacteria. Partnership: **DTU-Aqua**, SDU, DSC.
5. Management of extraction culture: Economic analysis, prizing of environmental service and management models of extraction culture including a tradable permit system. Partnership: **NERI-SYS**, KU-FOI.
6. Output: Analysis of bio-magnification of toxic substances from water to mussel meal, evaluation of different options for utilisation of extraction culture blue mussels. Partnership: **NERI-MAR**, DSC, DTU-Aqua.

WP1 is the core work package (figure 1) and the test unit established will be the platform for or deliver results to the other work packages. The unit will deliver input to WP3 on production volume and nutrient removal, to WP5 on costs of production and to WP6 mussels for analysis for toxic substances and sizes and numbers of mussels at given harvest times. The unit will be centre for studies of environmental impact in WP2. Measurements of growth and source of carbon and nitrogen incorporation will use the unit as a reference point in WP4. Results from WP2 and WP4 will feed into the modelling in WP3 that in turn will feed results into the management model in WP5. Hence, work packages are closely interlinked and dependent on interaction and exchange of data and deliverables.

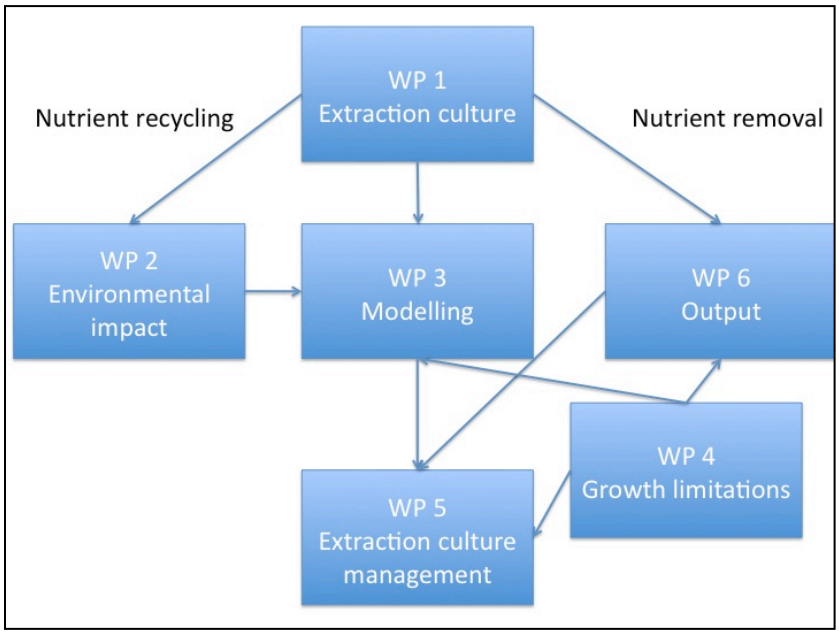


Figure 1. Schematic representation of the MUMIHUS work package organisation.

In addition to the scientific work packages mentioned above, 2 major tasks within the project are an inherent part of the MUMIHUS organisation, i.e. project management and dissemination and contact with stakeholders. Dissemination and contact with stakeholders are key components of MUMIHUS and will be represented in the project management. The scientific manager and a steering committee consisting of the scientific manager, the work package leaders and the administrative manager conduct project management. Work package leaders will be responsible for project deliverables and milestones and the steering committee for the overall integration of the project. Communication and meetings within work packages will vary in relation to the specific tasks and the partnership. Overall scientific progress, dissemination of results and contact to international shellfish research networks will be the responsibility of the steering committee, for the latter in collaboration with the MUMIHUS international partners. The project manager will be in charge of overall management and shall ensure that collaboration and exchange of information is working and that progress is achieved. The administrative manager will be responsible for financial administration and NERI-MAR has experience with DSF grants (e.g. "ECODYN and "Regimeskift i Limfjorden"). An annual meeting for all participants will be held, where results will be presented and working plans discussed. The first project meeting will be a "kick-off" meeting held in March 2010. The subsequent annual project meetings will evaluate progress and used as a forum for discussion of next years work and if adjustments are required.

MUMIHUS contributes to researcher recruitment with two PhD students and one post doc position. Research training of the PhD students and the post doc will take place through the universities with which the students and post doc will be affiliated. The supervisor and the relevant wp

leaders are responsible for study progress of the students and the post doc. In addition to specified PhD projects, a number of targeted master student projects can be contained within the project.

MUMIHUS will form an advisory board with participation from the Limfjorden Council (municipalities around the Limfjorden), The Agency for Spatial and Environmental Planning under the Ministry of Environment, The Association of Mussel Fishermen and Industry, Limfjorden Central Association of Fishermen, Danish Aquaculture Shellfish Branch and industrial partners. The advisory board will meet at the project kick-off, mid term and at the end of MUMIHUS. The advisory board will act as a source of inspiration to the project and the prime link to supposed end users.

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