B1.

BIOFiltration and AQuaculture: an Evaluation of Hard Substrate Deployment Performance within Mariculture Developments

BIOFAQs

Part B
Description of Scientific/technological objectives and workplan

15 November 1999

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B3 Objectives and expected achievements

The mariculture industry in Europe exists on a pan-European scale. Finfish farming is predominated in north European waters by the culture of Atlantic salmon (*Salmo salar*); southern European countries have widespread cultures of sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*). In addition there are large mariculture industries based on shellfish farming in most European coastal waters. However, a significant proportion of mariculture is undertaken under intensive farming conditions often in semi-closed or open conditions. Waste food and faeces from these farms are dispersed in the water columns either below the farm or in the direction of the prevalent hydrological regime and can result in significant accumulations of organic matter (OM) accumulation. In Atlantic salmon culture, it is estimated that between about 900 kg of carbon [1] and 55 kg of nitrogen [2] are released into the environment for every tonne of salmon harvested. Where farms are large industrial concerns, the impact can be equated to raw sewage outputs of medium-sized human conurbations [3]. The effects of these large, often concentrated, impact sources can be substantial on the surrounding sea beds resulting in sediment anoxia and hydrogen sulphide buildup (e.g. [4,5]). Such geochemical changes usually cause substantial alteration in the composition of the benthic and epibenthic biota below the fish farms [6]. Organic matter will accumulate beneath fish farms when the depositional flux exceeds the combined losses due to benthic degradation and consumption and advective processes (resuspension, dissolution). Where chemotherapeutants, antifouling agents and/or antibiotics are employed, then the ambient marine sediments and water column can contain elevated levels of a cocktail of contaminants. Organic enrichment associated with mariculture has obvious and well-documented environmental impacts [reviewed in 7]. However, in addition, where benthic impacts interact with the water column, the health and growth rates of the target culture species can be impacted with deleterious effects on the economic performance of the farm [5].

Various solutions have been proposed to reduce organic enrichment in the sediments below mariculture cages or rafts. For example, there have been attempts to collect particles falling from the farms, remove detritus from the seafloor using submersible pumps, and harrowing the sediments to accelerate recovery [reviewed in 8]. However, most of these techniques are not practical and add a significant cost burden to the farm operation. An alternative option is to deploy hard substrate structures around or below fish farms to act as biofilters. Biofilters are commonly employed in tank-based aquarium and culture systems where a degre of water recirculation is employed. They maintain the condition of the recirculating water by removing significant amounts of the nitrogenous input through biological action. Biofilters facilitate aerobic microbial breakdown of the OM released from the farm by providing a large surface area for microbial or higher order animal colonization in oxygenated water. OM decomposition is mostly a function of microbial processes and aerobic microorganisms are more efficient at OM decomposition than anaerobes [9]. Thus a substantial part of the particulate and dissolved OM absorbed by biofilter organisms are metabolized (respired) to CO_2 and H_2O and thereby naturally removed from the system. It is entirely feasible that the effectiveness of biofilter use in tank-based recirculatory systems can be transferred in a modified fashion to the mariculture industry. Pilot studies have reported some beneficial effects of biofilter use in association with mariculture where they have acted to take up and mineralize some of the organic and inorganic matter released from the cages thereby reducing benthic enrichment [10, 11]. By reducing the flux of OM from the cultures to the benthos, the biofilters should facilitate recolonization of impacted environments by associated macrofauna and may themselves provide additional habitat for passive colonization.

Therefore, the overall objective of this programme is to assess, model and enhance the biofiltering performance of hard substrate or artificial reef deployments either under or close to intensive mariculture concerns. This assessment will primarily quantify performance in terms of surplus nutrient reduction in the immediate vicinity of intensive mariculture through field measurement, mesocosm experimentation, and adaptation of existing mariculture-based prediction models. The programme will also investigate potential improvements in design to optimise performance.

Quantifiable environmental improvement will benefit the European mariculture industry through enhanced growth and survival of the mariculture species, but will also add value to the environment. Placing these benefits into a full cost/benefit analysis will give clear indications as to the economic worth of combining hard substrates within prescribed areas of mariculture. A final part of the proposed programme will examine use of the hard substrate deployments during and after exposure to the mariculture. If nutrient and/or particulate loading is high, then there may be a requirement to aid performance through cleansing operations. If low, then there is a possibility that animals of commercial importance could be harvested periodically. Measurement of recovery post-exposure will be undertaken. The use and placement restrictions of hard substrate deployments in association with mariculture may be subject to legislative processes, or may require the development of implementation guidelines. Recommendations will be made at the conclusion of the programme.

A complementary aim of this project is to produce legal and management guidance for regulatory bodies within the partner countries in relation to the use of hard artificial substrate as a biofilter for the mitigation of the environmental effects of aquaculture. This will be alongside a pan-European and global review of regulatory models, which is aimed at extrapolating the guidance to the multinational (particularly pan-European) level. There are a few legal studies that have been undertaken at a pan-European and global level with relevance to satisfying this objective, notably with respect to the use of artificial reefs, coastal planning and management and the governance of marine aquaculture. However, while the scope, coverage, detail and application of these studies makes them an important source of information and legal interpretation, they are not targeted at the issue in question, nor provide the country- and context-applicable advice necessary to ensure that the use of artificial substrate as a biofilter is both feasible and appropriately managed in Europe.

The expected achievements of the legal review will include the satisfactory deployment of the experimental artificial substrate within the project, the production of a single pan-European legal reference source, and the identification of country and context specific modifications to the existing regimes to provide for their provision and governance. As a bi-product of these outputs and the fact that the legal framework will inevitably be a composite of international and national regulations developed for other purposes, the range of regulatory and management frameworks assessed and documented will extend to, *inter alia*, the legal and management frameworks governing:

- marine aquaculture,
- environmental management (including pollution mitigation),
- coastal planning and management and
- artificial reef deployment.

The project will therefore have three overall themes: to quantify the validity (effectiveness) of biofilter use in association with mariculture within both economic and environmental frameworks on a pan-European scale; to optimise biofilter designs and placement protocols in line with geographical differences and validated model predictions; and to examine the environmental and regulatory options governing post-biofilter usage. In meeting these objectives, the project will deliver a comprehensive trans-European assessment of the environmental, social and economic benefits of biofilter deployment in association with mariculture concerns and produce guidelines on the regulatory framework required for such deployments.

B4 Contribution to programme/specific action objectives

The study contributes to several elements of the Fifth framework Programme "*Quality of Life and Management of Living Resources*". In particular it contributes to the key action area of "*Sustainable fisheries and aquaculture*" (Section 5.1.2) and the interactions between the environment, fisheries and aquaculture (Section 5.1.2, part 1). The study also contributes to the improvement of aquatic production (Section 5.1.2, part 3), and assists in the socio-economic assessment of life science and technology aspects (Section 13) through the development of indicators and knowledge bases relevant to public policy decision making and regulation (Section 13.1) and the analysis of links between life sciences, technologies and policies (Section 13.2).

Interactions between environment, fisheries and aquaculture (Section 5.1.2, part 1)
The study will provide research that will focus on methods and strategies that aim to reduce the undesirable effects of the interactions between the environment and aquaculture. Open-system mariculture can provide localized sources of organic enrichment through farm effluents. The main objective of this study is to assess and optimise methods of minimising the impact of these effluents through hard substrate biofilter deployments. In addition, the farm effluents can contain traces of chemotherapeutants, anti-fouling agents and antibiotics. The use of biofilters in association with mariculture concerns could contain additional farm-related pollutants within the immediate fish farm locality and could even reduce the breakdown period.

Improvement of aquatic production (Section 5.1.2, part 3)
The health of farmed species can be adversely affected through poor water quality associated with the build up of organics in the vicinity of farm cages. As well as affecting health, poor water quality can also detract from the sale price of the final product and the growth rates. Therefore, there are both animal health and economic issues associated with environmental degradation, in addition to the whole quality of the environment criteria. A reduction in the organic loading obtained through biofiltration will contribute positively to all of these factors.

Socio-economic aspects of life sciences and technologies (Section 13)
Through both an examination of the pan-European legal and regulatory framework for biofilter use in association with mariculture concerns, and the undertaking of a full economic cost/benefit analysis, the study addresses all the main requirements of this section. Study deliverables will include:

- the development of appropriate strategies and models that will add to competitiveness and sustainable development
- a regulatory framework for the deployment and management of biofilters
- reports in the public domain that will aid the public's understanding of the potential benefits to the use of biofilters
- a full assessment of the needs of all user communities.

B5 Innovation aspects

One of the main concerns regarding net cage mariculture in coastal waters is their impact on the marine environment. Surrounding the fish cages there are generally large populations of feral fish that congregate there to benefit from the unique conditions created by the farm [8]. The constant flux of feaces and other particles, such as uneaten food, falling from the net cages leads to organic matter (OM) accumulation on the seafloor and eventually to anoxia and buildup of hydrogen sulfide in some sediments (e.g. [4]). Such geochemical changes usually cause substantial alteration in the composition of the benthic and epibenthic biota below the fish farms [6]. Organic matter will accumulate beneath fish farms when the depositional flux exceeds the combined losses due to benthic degradation and consumption and advective processes (resuspension, dissolution). Various solutions have been proposed to reduce organic enrichment in the sediments below the net cages, e.g. collection of the particles falling from the cages, collection of detritus from the seafloor using submersible pumps, harrowing the sediments, etc. (reviewed in [8]). However, most of these are not practical or economically feasible. An alternative option is to deploy hard substrates below fish farms in order to take up and mineralize some of the organic and inorganic matter released from the cages and thereby reduce environmental enrichment.

Hard substrates, that could take the form of artificial reefs, deployed below fish farms should facilitate aerobic microbial breakdown of the OM released from the farm by providing a large surface area for microbial colonization in the oxygenated water above the seafloor. OM decomposition is mostly a function of microbial processes and it appears that aerobic microorganisms are more efficient at OM decomposition than anaerobes [9]. Thus a substantial part of the particulate and dissolved OM absorbed by the reef organisms will probably be metabolized (respired) to CO_2 and H_2O thereby naturally removed from the system. Moreover, by reducing the flux of organic matter from the fish cages to the benthos, hard substrate deployments should enable macrofauna to recolonize the surrounding sediments, and eventually enable demersal fish and other invertebrates to return to the region as well.

There has never before been a trans-European assessment of biofilter use in asociation with mariculture. European mariculture concerns are situated over close to the maximum longitudinal and latitudinal spread possible in Europe. Sea water and benthic physical and chemical conditions vary greatly with the geographical location, as do the species that are being cultured. Therefore it is possible that biofilter performance will differ with each location tested. In addition, because the project is based on assessing performance, there is also the requirement to standardise analytical methodologies. Agreed measurement protocols will aid the development of standardised assessment tools for determining environmental impact parameters. This will be supported by an impact model that will be transferable between European states with mariculture concerns.

There has been no prior legal analysis of the question of the use of artificial substrate as a biofilter to address aquaculture impacts, nor explicit legal provision within regulatory regimes in Europe. To-date literature in relevant areas in confined to the small body of secondary literature which has addressed parallel issues, inter alia: artificial reef deployment [12 – 15], aquaculture [16-18], marine ranching and open mariculture [19 – 21] and environmental law [22 – 23]. The growth of science in the marine environment often outpaces legal research, just as it does the development of law itself. This is not only true for this particular application of artificial substrate, but also allied activities, such as artificial reef development per se and marine aquaculture. The legal provisions for these existing marine activities are often extrapolations from the regimes governing other activities (e.g. fisheries) or narrowly focused (e.g. inland aquaculture), such that their cross-application to govern biofilters is not necessarily easy or appropriate [15, 21].

The legal regimes governing biofilters in Europe will ultimately be a plethora of international and national regulations which were primarily developed for other purposes and are, therefore, not necessarily well adapted to the context in question. Some existing regimes could be readily applied to, or adapted to provide the appropriate regime for the deployment and management of the concept, while others could potentially act to prohibit or limit the effectiveness of the technology or confine it to certain circumstances or locations. In evaluating the potential and effectiveness of the concept for European applications, a review of the existing legal regimes is therefore essential.

Legal innovation will not only be in respect of biofilters but also in respect of documenting the legal regimes pertaining to these parallel issues within Europe (a necessary bi-product of the legal review), providing wider applicability to the results. Further to which, the application of Comparative Legal Analysis will develop a basis of comparison and set of criteria, rules and caveats for the application of the analytical framework to the

evaluation of the governance of other marine and coastal activities. Comparative Legal Analysis does not involve a distinct branch of substantive law but is a long standing and evolving analytical framework for the comparison of laws using the rules of both public and private law and certain analytical paradigms to:

- identify different ways of addressing functional requirements, resolving problems and conflicts
- assess the effectiveness of legal regimes and identify their strengths and weaknesses in respect of resolving these problems and conflicts
- identify the factors in success
- elicit an enriched supply of solutions , potentially “better solutions”, to address specific functional requirements, and
- identify strategies to improve and implement solutions and identify the opportunities, constraints, caveats and conditions of implementation.

This project will draw on prior developments in the field (e.g. [24 –27]) and development them further.

B6 Project Workplan

a. Introduction

The project is comprised of six work packages:

WP 01: Review of current knowledge base
WP 02: Mariculure impact modelling
WP 03: Mesocosm studies
WP 04: Field studies
WP 05: Legal analysis and regulations
WP 06: Cost/benefit economics

In addition to the work packages outlined above, a co-ordination activity (WP 00) will also be undertaken by the co-ordinator. This is an administrative rather than research activity.

The research objectives of the project are presented as six work packages. However, within this structure there are cross cutting themes that may be addressed by one or more of the work packages (refer to the project PERT diagram). The themes adopt the following disciplinary split:

Theme A: To quantify the validity (effectiveness) of biofilter use in association with mariculture within both economic and environmental frameworks on a pan-European scale

Theme B: To optimise biofilter designs and placement protocols in line with geographical differences and validated model predictions

Theme C: To examine the environmental and regulatory options governing post-biofilter usage

WP01. To provide a primary and grey literature review of the current knowledge base relating to mariculture impacts on a pan-European scale; to include a review of existing biofiltration methodology. From this review will come a synthesis of current biofiltration techniques and how they may be adapted for European open-system mariculture industries.

WP02. To advance existing fish farm impact/dispersal models to predict the performance of biofiltration deployments. Field validation of predictive environmental impact models will be employed to further develop and validate models that can predict the economic and environmental benefits of biofilter deployments in association with mariculture development.

WP03. To undertake a programme of mesocosm experiments that will assess biofilter design and performance over a range of temporal scales, a range of environmentally relevant physico-chemical parameter variations and under differing loading rates. The full assessment of performance will incorporate determinations of energy and nutrient fluxes, examination of fallowing dynamics and investigation of biofilter design (location criteria and physical characteristics within a geographical variant context) with specific reference to determining surface area availability requirements.

WP04. An extensive fieldwork programme will be undertaken using, where practicable, test biofilter deployments in association with ongoing mariculture concerns. The fieldwork programme will yield data that will be employed to verify the results from the mescosm (WP03) and modelling (WP02) work packages.

WP05. To review the current regulatory status of mariculture impacts and hard substrate deployments in European waters and to ascertain the likely acceptance of biofilters within these regulatory frameworks.

WP06. To prepare pan-European cost/benefit analyses of biofilter deployment in association with mariculture development with specific reference to environmental value.

The structure of the project, indicating the proposed timetabe, the project deliverables, the project milestones and the partner inputs are illustrated in the following tables. Deliverables are specific to each work package, some milestones are dependent on more than one work package.

b. Project planning and timetable

Project Timetable

	MONTH																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
WP00																																				
WP01																																				
WP02																																				
WP03																																				
WP04																																				
WP05																																				
WP06																																				

Workshops (partner)	**P1**											**P5**											**P3**													
PCMs	**1**					**2**						**3**					**4**						**5**						**6**						
Ms													**1**				**4**		**5**									**3**					**2 6 7**	
Ds									**1**			**2 3 4 5 6**							**7**				**8**					**9**					**10 11 12 13 14**	

Key:

Month: month from start of project
WP00-WP06: work packages 00 to 06
P1, P3, P5: project partners 1, 3, 5
PCMs: Project Co-ordination Meetings
M1-Mn: project milestones
D1-Dn: contract deliverables

c. Graphical presentation of the project's components

The Project is divided into work Packages. Each Work Package is further broken down into individual components that equate approximately to the project objectives.

WORK PACKAGES		WORK PACKAGE AND COMPONENT DESCRIPTIONS
WP00	0.1	Project co-ordination
WP01	1.1	A primary and grey literature review of the current knowledge base relating to mariculture impacts on a pan-European scale.
	1.2	A review of existing biofiltration methodology
	1.3	A synthesis of current biofiltration techniques and how they may be adapted for the European open-system mariculture industries
WP02	2.1	To advance existing fish farm impact/dispersal models to predict the performance of biofiltration deployments
	2.2	Field validation of predictive environmental impact models
	2.3	To develop and validate models that can predict the economic and environmental benefits of biofilter deployments in association with mariculture development.
WP03	3.1	To assess biofilter design and performance over a range of temporal scales, a range of environmentally relevant physico-chemical parameter variations and under differing loading rates.
	3.2	To determine energy and nutrient fluxes within WP3.1 with the objective of estimating the conditions under which biofilters continue to function without the requirement for intervention (removal or cleaning).
	3.3	To assess the dynamics of biofilter fallowing in order to determine recovery rates with or without direct intervention
	3.4	To investigate reef design (location criteria and physical characteristics within a geographical variant context) with specific reference to determining surface area availability requirements.
WP04	4.1	To establish and verify field measurement criteria that will input into the required model verifications (WP2.2) with the objective of developing normalised, pan-European protocols applicable to the impact models.
	4.2	To undertake experimental biofilter deployments in the field situation within standardised and replicated protocols in order to assess in field performance in detail.
	4.3	To make field measurements of energy and nutrient fluxes both with and without biofilter placements in order to quantify changes that may be occurring on deployment of biofilters.
	4.4	To undertake detailed pre- and post-deployment hydrographical profiles for model validation purposes.
	4.5	To record and quantify the rates and biomasses of biological settlement and accumulation on the biofilters. Special reference will be given to species with known commercial importance.
	4.6	Where biological communities develop on or around the experimental biofilter deployments there will be a requirement to quantify bioaccumulation both in terms of potential pollutant uptake and from promoting biofilters as nutrient sinks. Some work will be carried out in order to identify potential biomarkers of filter quality. Bioaccummulation studies are of primary importance where harvesting of commercially important species is a possibility (see WP4.5).
	4.7	An investigation of the fallowing dynamics of the biofilters will be undertaken once significant biofiltration in the field has been established. This is of particular importance where pollutant accumulation is a possibility.
WP05	5.1	To review the current regulatory status of mariculture impacts and hard substrate deployments in European waters and to ascertain the likely acceptance of biofilters within these regulatory frameworks.
	5.2	To evaluate the transferability of legal models within the European context.
	5.3	To develop an analytical tool within the framework of comparative legal analysis.
WP06	6.1	To prepare pan-European cost/benefit analyses of biofilter deployment in association with mariculture development with specific reference to environmental value.

For each Work Package, and for each component part of each Work Package, the partner contributions (in man months for the total project duration) are given below:

WORK PACKAGES		PARTNERS							
		P1	P2	P3	P4	P5	P6	P7	P8
WP00	0.1	18.0	6.0						
WP00 Sub-total		18.0	6.0						
Total		**24.0**							
WP01	1.1	2.0	2.0		4.0	2.0		0.3	
	1.2	1.0	2.0					0.1	
	1.3	3.0	2.0	3.0				0.1	
WP01 Sub-total		6.0	6.0	3.0	4.0	2.0		0.5	
Total		**21.5**							
WP02	2.1	8.0	2.0						
	2.2	4.0	4.0					1.0	
	2.3	5.0	3.0					1.0	
WP02 Sub-total		17.0	9.0					2.0	
Total		**28.0**							
WP03	3.1	10.0	8.0			18.0			
	3.2	3.0	5.0			10.0			
	3.3	3.0	2.0			8.0			
	3.4	6.0	5.0	2.0		4.0			
WP03 Sub-total		22.0	20.0	2.0		40.0			
Total		**84.0**							
WP04	4.1	4.0	4.0	3.0	1.0	2.0		0.6	
	4.2	3.0	4.0	3.0	2.0	18.0		5.0	
	4.3		8.0	2.0	20.0	18.0		0.3	6.0
	4.4	3.0	3.0	5.0	20.0	4.0		0.3	6.0
	4.5	3.0	8.0	12.0	16.0				5.0
	4.6	3.0	5.0	3.0	15.0			0.3	5.0
	4.7	2.0	2.0	2.0	8.0				2.0
WP04 Sub-total		18.0	34.0	30.0	82.0	42.0		6.5	28.0
Total		**240.5**							
WP05	5.1	1.5		2.0	4.0	3.0	5.0		
	5.2					1.0	5.0		
	5.3						2.0		
WP05 Sub-total		1.5		2.0	4.0	4.0	12.0		
Total		**23.5**							
WP06	6.1	1.5	1.0	1.0	2.0		16.0		
WP06 Sub-total		1.5	1.0	1.0	2.0		16.0		
Total		**21.5**							
Total		**84.0**	**76.0**	**38.0**	**92.0**	**88.0**	**28.0**	**9.0**	**28.0**
		P1	P2	P3	P4	P5	P6	P7	P8
		PARTNERS							

d. Detailed project description broken down into workpackages

WP1 Workpackage List

WP No	Workpackage Title	Responsible Participant	Person months	Start Month	End Month	Phase	Deliverable No
00	Project Co-ordination	1	24.0	0	36	SR	D14
01	Review of Current Knowledge Base	1	21.5	0	12	SR	D2, D3
02	Modelling	1	28.0	9	36	SR	D10
03	Mesocosm Studies	5	84.0	4	30	SR	D7, D9, D12
04	Field Studies	2	240.5	3	36	SR	D1, D8, D11, D12
05	Legal analysis and regulations	6	23.5	0	12	SR	D4, D5, D6
06	Cost/benefit economics	6	21.5	25	36	SR	D13

DL Deliverables List

Deliverable No	Deliverable title	Delivery Date	Nature	Dissemination level
1	Field deployment of some biofilters in association with mariculture concerns (WP04)	9	O	PU
2	Report summarizing the findings of the review caried out as part of WP01	12	R	PU
3	Bibliographic database resulting from the review carried out as part of WP01	12	O	PU
4	Synthesis of existing legal regimes and revisions desirable by case study and pan-European (WP05)	12	R	PU
5	Bibliographic database of relevant legal and regulatory literature relating to marine hard substrate deployments (WP05)	12	O	PU
6	Legal compendium and management guidance for biofilter deployment(WP05)	12	R/O	PU
7	Mesocosm-derived design criteria for biofilter modelling and field deployment/revision (WP03)	20	O	PU
8	Collation of field data required for environmental model validation (WP04)	24	O	PU
9	Mesocosm-derived determinations of sustainable biofilter loading rate estimates (WP03)	30	O	PU
10	A field-validated predictive model (with user-friendly interface) for determining changes in mariculture-related environmental impacts attributable to biofilter deployment (WP02)	36	O	PU
11	A collated detailed assessment of the field performance of biofilters (WP04)	36	R/O	PU
12	An assessment of fallowing dynamics of biofilters (WP03, WP04)	36	R/O	PU
13	Summary of cost/benefit analyses of biofilter deployments (WP06)	36	R	PU
14	Final programme reports (WP00)	36	R	PU

These deliverables will be supplemented by the production of academic papers for publication in the international peer-reviewed literature and conference papers for presentation at international conferences through out the project.

Detailed description of work plan

WP00: Project co-ordination

This is an administrative task that lasts the lifetime of the project. The object of this task is to ensure that the project meets deadlines through the organisation of a series of co-ordination meetings. Project co-ordination, therefore, involves arranging meetings, initiating communications, co-ordinating the production of reports and accounts, and producing interim progress reports to the EC.

The main co-ordination tasks are sub-divided between the main project co-ordinator (Partner 1) and an administrative group (comprising three members drawn from Partners 1 and 2). The scientific programme will also be overseen by Partner 1 but with additional support from a scientific co-ordinator (Partner 2) who, in turn, will receive guidance from the Scientific Steering Group (made up of the principal investigators of each of the Partners). In addition to this, each Work Package will be lead by principal investigators from Partners 1, 2, 5 and 6.

During the course of the project, there will be 3 technical workshop meetings with the full project membership attending. In addition there will be 6 Project Co-ordination Meetings (PCMs) attended by the Scientific Steering Group. Three of the PCMs will be held during the technical meetings in order to minimise travel costs.

WP01: Review of Current Knowledge Base

There has been considerable research on various aspects relating to environmental impacts of mariculture. However, this literature, and the research it is based on, is disparate and unco-ordinated, and contributes little in the way of trans-European strategic advice or suitable frameworks of analysis for use by regulating authorities or mariculture concerns. The first part of this Work Package will, therefore, provide a strategic review of the primary and grey literature relating to the environmental impacts of mariculture.

The use of biofilters offers a potential method for reducing deleterious impacts of mariculture. Although some preliminary marine deployments have been carried out in the past, there is little direct evidence of biofilter utilization in the field. However, biofilters are used extensively in recirculating, or partially recirculating seawater systems and a literature exists that explores optimal performance indicators. A review of this literature will form the basis for initial biofilter design and the revision of existing biofilters.

During the completion of the two above review areas, a synthesis of current biofiltration techniques and how they may be adapted for the European open-system mariculture industries will be produced. This will integrate with the legal and regulatory reports produced from WP05.

WP02: Impact/dispersal modelling to predict the performance of biofiltration deployments

An operational Lagrangian model has been developed by Partner 1. This model uses measured currents from multiple layers to determine deposition rates form cage farms. Necessary parameters include: current profile with depth; feed particle size and hence settling velocity; waste feed as a function of feed input, which varies over time taking into account fish growth; and resuspension rates which have been calibrated using particle tracer experiments. The net flux to the bed has been empirically related to infaunal community structure at a large number of fish farm sites. Further planned development (independent of this project) of this model will include predictions of sediment oxygen demand and nitrogen flux.

To allow predictions of biofilter effects on the remineralisation process, this model will be developed to include the interaction of particulates with the reef structure. The reef structure will modify the impacts in several ways:

- By reducing near bed current flows the biofilter will tend to trap particulates thereby reducing resuspension. This will have differing consequences depending on whether resuspension is an important process at a site.
- The biofilter will cause down-current turbulence that may lead to increased erosion or increased deposition depending on the physical structure of the reef and the prevailing current regime.
- The biofilter will cause a change in biodiversity, an increase in oxygen concentration, and an increase in nitrogen flux depending on particulates flux.

In order to accommodate these and other potential modifications to impact a biofilter module will be added to the current model that will characterise the physical size and surface area of the filter and use standard

equations to describe the physical and then biogeochemical response. This module will then be tested using data from the mesocosm and fieldwork packages.

The modelling process will, in significant measure, define the key mesocosm (WP03) and field experiments and measurements (WP04) and will, through sensitivity analysis, determine those factors of biofilter design which are most crucial to achieve the desired function for a specific site.

The model will provide information on the increased carrying capacity of a site (on environmental quality standard criteria e.g. some index of diversity, where such exist) which might be released as a consequence of biofilter installation. This information will be crucial to the cost benefit analysis to be carried out in WP06.

WP03: Assessment of biofilter design and performance using mesocosm-based experimentation

Mesocosm experiments have been previously used to assess the degree of environmental impact, the behaviour of such impacts and the intervention and non-intervention recovery rates. The mesocosm is a large aquarium tank (ranging in volume from 1-40m^3) into which environmental impact can be simulated. Potential experimental variables, such as seawater temperature and salinity, the degree and type of impact, and the temporal scale of the experiment, can be standardised in a way that is not possible in the field. There is a lot of background research that validates the transfer of results from mesocosm experiments into the field situation. Therefore, using established experimental protocols and assessment techniques a series of experiments will be carried out to assess biofilter design and performance over a range of temporal scales, a range of environmentally relevant physico-chemical parameter variations and under differing loading rates.

The full assessment of performance will incorporate determinations of energy and nutrient fluxes. These will be measured in the same way as the field experiments (WP04). It is proposed to concentrate initially the experiments on a scaled down versions of biofilters that represent the same physical design criteria as that established in the standardised field deployments (WP04). However, there will also be a requirement to investigate optimising the designs for future deployments, and so an element of the mesocosm research will be to examine new designs.

In addition to the determination of primary biofilter design criteria the mesocosm programme will invesigate performance under a matrix of positional variation. Under some loading conditions, the biofilter performance may be compromised if placement is directly below the input source. Diluting the input source and increasing the available filtration surface area can be achieved by moving the biofilters further away from the source. However, this may increase costs but may be more effective. These design criteria variations will be included within the impact and econimic modelling components of the project (WP02 and WP06, respectively).

Most mariculture practices incorporate an element of fallowing in their production cycle. If a biofilter was associated with a fallowed site, the concern management may wish either to retain the filter in position to facilitate recovery, or move the filter to a site on ongoing production in order to minimise investment costs. The mesocosm experiments will address the ability of the filters to recover post-input. Experiments will also determine the degree of resuspension that may occur if the biofilters were recovered on initiation of fallowing. Where pollutants are present within the input OM, a determination of potential pollution transfer in or release by the biofilters will be made.

WP04: Assessment of biofilter perfomance in field situations

This work package contains the fieldwork component of the overall project. The deployment of biofilter units in areas either under or close to active mariculture sites will be used to make field validations of biofilter performance. In addition, the deployments will establish and verify field measurement criteria that will input into the required model verifications (WP02) with the objective of developing standardised, pan-European protocols applicable to the impact models. It is intended to standardise biofilter design in order that trans-European comparisons of performance can be made. However, there will be a requirement to assess other designs in less detail. Where this takes place, it will be within the context of the standard design.

There will be two fieldwork approaches. In partner countries where biofilter deployments may require relatively low levels of regulatory compliance, the fieldwork will be designed to start with comparisons of the

degree of environmental impact with or without biofilter deployment[1]. The secondary approach will be to undertake periods of pre- and post- biofilter deployment assessment. In all cases there will be a requirement for both the deployment and non-deployment sites to have at least one level of replication.

A number of analytical assessment techniques will be used in order to determine biofilter performance. Some of these techniques, such as hydrographical profiling for example, are standard input requirements for the impact modelling component of the project (WP02).

The sediment geochemistry and the structure of benthic communities provide a valuable means for assessing the effects of enrichment on the sedimentary environment since they integrate several environmental factors over time. This WP will assess the efficiency of the reefs as a means of reducing benthic enrichment below fish cages by detecting changes in the benthic community at the part of the sea bed covered by reefs. Samples in sediment profiles for identifying geochemical variables (OM, redox, N, P, ATP, pigments, water content) as well as samples for macrofaunal and meiofaunal analyses will be collected from the sea bed under the cages in areas covered by the reefs as well as in areas directly receiving OM from the overlying cages. Community structure and diversity will be investigated using univariate and multivariate analysis for the detection of community response to benthic enrichment and for the analysis of temporal succession of the communities during the expected recovery phase after the establishment of the reefs.

This WP will also assess the efficiency of the reefs as a means of retaining particulate and solute wastes of the fish farming. CHN analysis for the determination of particulate Carbon and Nitrogen fixed on the reefs and determination of total Phosphorus will be carried out at different temporal scales in order to infer rates of removal of nutrient solute wastes from the water column (N & P) and the quantities of OM that were prevented from reaching the sea bed.

The determination of rates of energy flow or biological production in and on both the hard substrates deployed, and the surrounding soft(er) sediments will be undertaken using respirometer chambers. Enclosed chamber (respirometer) experiments have a long history in examining the respiratory exchange and thus the energy utilization of animals. Sediment community oxygen consumption (SCOC) uses respirometers to study benthic processes. Light and dark bottle incubation are routinely used to determine the rates of respiration and production of water column plankton. Chamber incubation has been applied to the study of single species of algae, corals and sponges. The results of these field experiments will contribute to an understanding of the turnover of carbon by the ecological systems and thus their ability to deal with increased organic loads.

The fieldwork programme will record and quantify the rates and biomasses of biological settlement and accumulation on and/or around the biofilters. Special reference will be given to species with known commercial and ecological importance. Where biological communities develop on or around the experimental biofilter deployments there will be a requirement to quantify bioaccumulation both in terms of potential pollutant uptake and from promoting biofilters as nutrient sinks. Some work will be carried out in order to identify potential biomarkers of filter quality. Bioaccummulation studies are of primary importance where harvesting of commercially important species is a possibility. An investigation of the fallowing dynamics of the biofilters will be undertaken once significant biofiltration in the field has been established. This is of particular importance where pollutant accumulation is a possibility.

WP05: Legal analysis and recommendations

This work package will facilitate the satisfactory deployment of the experimental artificial substrate and compliance with all legal and administrative requirements during the project. The main objective of the work package is, however, to produce legal and management guidance for regulatory bodies within Europe and its member countries in relation to the use of hard artificial substrate as a biofilter for the mitigation of the environmental effects of aquaculture. This will initially be undertaken for the partner countries to assist in the deployment of the experimental artificial substrate and, subsequently, on a pan-European basis. As part of the process of satisfying this objective, the following sub-objectives will also be addressed: (i) to evaluate the transferability of legal models within the European context, and (ii) to develop an analytical tool within the framework of comparative legal analysis.

[1] *NB. Some preliminary biofilter deployments have already been undertaken by some of the project partners, and so the fieldwork component of the project is not vulnerable to any form of regulatory non-compliance. Other partners have discussed this proposal with their regulatory bodies, and compliance is thought highly probable.*

This work package will involve: a desk-base review of the literature; the development of an analytical framework; the identification and collation of appropriate legal materials; the review of legal materials in accordance with this analytical framework; the clarification of regulatory processes in practice; stakeholder analyses within the case study countries; the clarification and initiation of applications in accordance with legal requirements for the deployment of the experimental units; and the production of deliverables and recommendations in accordance with the objectives.

The desk-based review of the literature will initially cover frameworks of analysis, notably comparative legal analysis, to facilitate the clarification of the appropriate analytical frameworks for the whole work package and the criteria, rules and caveats governing their use. The sources of information used will include both general and legal specific bibliographic sources (eg. Bids, Euro Law). The partners responsible for the legal review will develop on this initial literature review a common analytical framework, by which to undertake their respective responsibilities to ensure pan-European comparison. This will notably draw from the field of comparative international law and although there are various paradigms/ approaches within comparative international law, that of comparative functionalism would seem the most relevant to the question in hand. The aim of comparative legal analysis is to facilitate the ordering and comparison of legal and paralegal institutions, techniques and regulations, which comparative functionalism achieves by reference to the functions fulfilled and to both legal documents and action. The constituent tasks of comparative legal analysis will then be allocated among the partners and will cross the component stages of analysis, notably: function definition, the legal search, legal interpretation, construction of systems/models and application of the findings.

The definition of functions pertains to the identification of the issues, problems and tasks that management needs to address. Many legal systems essentially require the same functions to be fulfilled, yet addresses them by different means. By identifying and focusing on these functions and establishing how a particular legal system addresses them the basis of comparison is established.

On the basis of the functional definition, the responsibilities and frame of the legal search will be set, notably the identification and collation of appropriate legal materials. This will no doubt include pertinent materials within the fields of law governing, inter alia, marine aquaculture, marine environmental management, coastal planning and management, property and use rights, fisheries management and artificial reef deployment. The literature review will identify regulatory frameworks both within Europe and beyond to establish the various regulatory models and the requirements for the effective provision and governance of biofilters. Both national and international legal frameworks will be considered. The identification and collation of appropriate legal materials will be European specific and in the first instance focused on the case study. The information sources used will be both CDRom and online legal bibliographies, e.g. FAOLEX, Lexis, EuroLaw, with the primary materials obtained either via these sources, via legal publications (eg. the EC Official Journal) or government agencies. As part of the process of data collation, the partners and external translation services will be instrumental in the translation of materials for use in the analytical process. Being in possession of an appropriate base of legal materials will be a key milestone of the project. Also, as part of this task, contacts and interviews will be made with government agencies responsible for the regulation of the industry to establish the mode of implementation and the administrative procedures undertaken within the regulatory process. This will be used to elaborate on the documented legal regime and identify the regulatory regime in practice. For the case study/ partner countries this will be supplemented by the identification of the mandates, objectives and priorities of the various stakeholder groups, both governmental and non-governmental, with respect to the deployment of artificial substrate as biofilters.

The legal interpretation of the results of the search will adopt the rules and due process of comparative analysis, which underwrite the rigour and validity of the interpretative process. These rules aim to avoid the pitfalls of mistranslation, misinterpretation and omission, which are often associated with linguistic and terminological problems, cultural differences, differences in the legal philosophy and ideology of legal systems, differences in rules of precedence and legal interpretation, and the varying nature and impacts of extra-legal rules. On the basis of the review, the necessary permits and authorisations for the deployment of the experimental units will be applied for and the various legal/regulatory and institutional models for the provision and governance of biofilters under current legal regimes within the partner countries and across European identified. Country specific briefs will initially be compiled in accordance with the framework of analysis. These will facilitate cross- country comparison: identifying, inter alia, the omissions, duplications, constraints and opportunities present within the current legal regimes and (in conjunction with examples from outside Europe) the production

of a typology of legal frameworks/models. The models identified will be validated via the general principles of:: model verification; clarification of the models being both feasible and within the bounds of expectation; and model comparison with historical scenarios and cases. On this basis, recommendations for country and context specific modifications to the existing regimes to provide for the provision and governance of biofilters will be identified. This will extend where possible to the opportunities, constraints and caveats facing their adoption and the transferability of the models identified within Europe.

The work package will be undertaken through a partnership of legal experts from each partner country, with responsibilities for the pan-European and global reviews assigned between the partners to ensure appropriate coverage and to make the most of each persons expertise and knowledge of legal systems.

Work package 06: Economic appraisal of hard substrate deployment in mariculture

Despite positive socio-economic effects associated with the development of aquaculture in Europe, concern has been expressed about the impact of fish farming on the marine environment and the prospects for its sustainability. (Folke and Kautsky, 1991 and 1992; Folke, Kautsky and Troell, 1994; Soley, Neiland and Nowell, 1994; Muir et al., 1999). Net cage mariculture is a particular cause of concern, amid evidence that the production methods hitherto practiced by many fish farmers lead to a number of adverse environmental impacts (e.g. seabed sedimentation, nutrification of the water column, eutrophication). These impacts may generate economic costs not only for fish farmers themselves (via negative feedback on production through reduced growth and survival) but also for society as a whole. For example, mariculture pollution may lower the output of other commercially valuable fish species and may degrade the marine environment in ways which reduce the flow of benefits to users and non-users (e.g. lower water quality as a result of greater tubidity and nuisance algal blooms may reduce the recreational or amenity value of a site). The challenge is therefore to find whether it is possible to mitigate these problems in an economically efficient way, and that in turn requires a comparison of the economic benefits of reduced pollution damage with the costs of the various schemes for achieving this goal. Biofiltration using hard substrates represents one such scheme, and the economic feasibility of this option will be analysed in detail.

The environmental economics literature forms the basis of a number of techniques which can address this problem, which is essentially one economic valuation (Dixon et al, 1988; Hanley and Spash, 1993; Kopp and Smith, 1993; Munasinghe, 1993; Pearce and Moran, 1994; Winpenny, 1991 and 1996; Royal Commission on Environmental Pollution, 1998; Whitmarsh, 1999). The methodology to be used in this work package will employ two basic approaches, the one focussing on the relative economic costs of different pollution prevention options (cost-effectiveness analysis) and the other involving an analysis of both the monetary benefits and the costs (cost-benefit analysis). (i) *Cost-effectiveness analysis*. In the context of this research proposal, CEA involves the specification of an environmental objective or target measured in terms of an agreed performance indicator (e.g. an x% reduction in BOD over a given period), and then seeks the least-cost way of achieving that goal. Prima facie evidence suggests that hard substrates deployed below fish farms are a practical and economically feasible option, but whether they are indeed the most cost-effective solution is one which needs to be confirmed empirically. (ii) *Cost-benefit analysis*. Placing a monetary value on the economic benefits of a project for mitigating the environmental damage caused by mariculture is necessarily complex, given that the positive effects of mitigation may be indirect and long term. Additionally, the benefits to society are quite likely to involve environmental changes which have no obvious market price attached to them but for which people would in principle be willing to pay. Water quality improvements, habitat preservation and increased biodiversity would be examples of this kind on non-market benefit. Methods for valuing such effects that are applicable in this instance are (a) *productivity-based methods* and (b) *preference-based methods*. Data for (a) will be derived from the results of the other work packages (e.g. in terms of a knowledge of the physical relationship between environmental quality change and fish catches) combined with information on the economic value of these changes based on market or surrogate prices. Data for (b) will come from two sources: firstly, a *contingent valuation survey* in order to assess public willingness to pay for measures that would result in reduced pollution damage and improved water quality; secondly, a *multi-attribute utility survey* to assess public preferences and trade-offs between different dimensions of the pollution-reduction problem.

Work package description

Work package number:	WP00
Start date or starting event:	0
No of partner responsible:	1
No of other partners involved:	2
Person months per partner:	
• Partner 1 (project co-ordinator)	18.0
• Partner 2 (scientific co-ordinator)	6.0

Objectives (max. 900 characters/200 words)

- To co-ordinate each component of the project and each partner's contribution;
- To arrange project workshops and co-ordination meetings;
- To ensure the project is running to schedule;
- To identify and rectify any problems that may arise during the course of the project;
- To co-ordinate and complete the administrative requirements of the project (e.g. cost statements, interim reports etc.);
- To co-ordinate and complete all project deliverables.

Description of work (max. 1500 characters/350 words

The project will have three workshops during it's duration where technical aspects of the work will be presented, discussed and revised where necessary. In addition, project co-ordination meetings (PCMs), comprising just the principal investigators, are to be held at approximately 5-6 month intervals, timed to ensure the satisfactory completion of the work packages: either in terms of planning, monitoring or reviewing the work undertaken within each work package. Any potential problems will be identified at the meetings, and a means of overcoming the problem devised by the project team. Three of these PCMs will be held during the workshops. The other three will occur in a 5-6 month period after each workshop. In addition to co-ordination meetings, remote communications (e-mail, bulletin boards and video conferencing) will also be used to ensure satisfactory progress on the project.

Deliverables (Max. 900 characters/200 words)

The only formal output from the co-ordination component of the project will be the interim and final progress reports and associated cost statements. Where appropriate, the proceedings of the workshops will be collated for dissemination purposes.

Milestones and expected results (max. 900 characters/200 words)

The milestones will be the submission of the interim progress reports. The expected results are that the project is running smoothly and to schedule.

Work package number:	WP01
Start date or starting event:	0
No of partner responsible:	1
No of other partners involved:	2, 3, 4, 5, 7
Person months per partner: *(i.e. those charged to the project)*	
• Partner 1 (co-ordinator)	6.0
• Partner 2	6.0
• Partner 3	3.0
• Partner 4	4.0
• Partner 5	2.0
• Partner 7	0.5

Objectives (max. 900 characters/200 words)

- To provide a synthesis of the existing primary and grey literature relating to the current knowledge base of mariculture impacts on a pan-European scale.
- To review existing biofiltration methodologies.
- To evaluate the transferability of biofiltration techniques to open-system mariculture.
- To provide an overview of the regulatory status of hard substrate deployments, with or without an association with mariculture, within a trans-European context.

Description of work (max. 1500 characters/350 words)

This work package will initially involve a desk-based review of the primary and grey literature and the outputs of past and current research of relevance to the project. This will include literature and research on the impacts of mariculture within Europe, existing methodologies employed for biofiltration (in closed, semi-close, or open systems), past works that have attempted biofiltration within a mariculture context and the legal/regulatory status of hard substrate deployments throughout Europe. Some of this literature and research has been previously identified in the context of other projects. However, this information will be up-dated and supplemented through searches on bibliographic databases and the internet.

The existing base of contacts with individuals and groups who are currently or have previously been involved in relevant research will be built on and invitations to attend the planned workshops will be made where appropriate to elicit the current state of knowledge and to obtain key information.

On the basis of the review, reports will be produced, detailing the transferability and applicability of the findings of the research and methodologies used to the European context.

Deliverables (Max. 900 characters/200 words)

- Targeted summaries of the findings of the work package
- A report summarising the findings
- Academic papers for publication in refereed journals
- Bibliographic database of relevant literature and research in Europe and globally

Milestones and expected results (max. 900 characters/200 words)

The publication of the full review will be milestone 1. The expected results within this milestone will be executive summaries, a summary report, academic papers and a bibliographic database. This review information will identify the practical, technological and legalistic possibilities for biofiltration use in association with mariculture, and will be used to focus and modify the research directions of the overall project.

Work package number:	WP02
Start date or starting event:	9
No of partner responsible:	1
No of other partners involved:	2,7
Person months per partner: *(i.e. those charged to the project)*	
• Partner 1 (co-ordinator)	17.0
• Partner 2	9.0
• Partner 7	2.0

Objectives (max. 900 characters/200 words)

- To advance existing fish farm impact/dispersal models in order to predict the performance of biofiltration deployments.
- To perform field validations of the predictive environmental impact models.
- To develop and validate models that can predict the economic and environmental benefits of biofilter deployments in association with mariculture development.

Description of work (max. 1500 characters/350 words)

The development and validation of models that successfully predict the environmental impacts of mariculture developments has been an essential area of regulatory advance over the past 10 years. Partner 1 has been a prime mover in the development of these models that have been adopted for both north European and Mediterranean mariculture developments. Using existing impact models this work package will utilize data obtained both from mesocosm experiments and field deployments to develop additional models, or revise existing ones, in order to provide a predictive tool that not only indicates the potential environmental benefits of biofilter use, but also presents the results within an economic context. The geographical partner spread of this project offers the opportunity to test and improve the models so that there is trans-European applicability for the models. In addition, Partner 7 in a recent collaboration with engineers, fishery scientists and mathematical modellers has produced design criteria for enhancing the fishery potential of coastal marine structures. This experience will be applied to the biofilter design work. Information on reef epibiota biomass and production from direct measurement and the literature will be used to contribute to the prediction model of biofilter performance.

Deliverables (Max. 900 characters/200 words)

- A field validated predictive model for determining the benefits of biofilter deployment on a farm by farm basis.
- The development of a user-friendly interface with supporting literature

Milestones and expected results (max. 900 characters/200 words)

This work package will deliver Milestone 2 of the project. This will be the development of a model that can predict changes in environmental impact caused by biofilter introduction. The model will be based primarily on mesocosm experiments and revised with input from field validation. The milestone will be completed by the finalised version of the model being packaged to enable third part usage.

The expected results are the satisfactory attainment of the work package milestones, the predictive model, a user-friendly software package for the model and supporting publications (academic papers and technical reports).

Work package number:	WP03
Start date or starting event:	4
No of partner responsible:	5
No of other partners involved:	1, 2, 3, 5
Person months per partner: *(i.e. those charged to the project)*	
• Partner 5 (co-ordinator)	40.0
• Partner 1	22.0
• Partner 2	20.0
• Partner 3	2.0

Objectives (max. 900 characters/200 words)

- To assess biofilter design and performance over a range of temporal scales, a range of enviromentally relevant physico-chemical parameter variations and under differing loading rates.
- To determine energy and nutrient fluxes with the objective of estimating the conditions under which biofilters continue to function without the requirement for intervention (removal or cleaning)
- To assess the dynamics of biofilter fallowing in order to determine recovery rates with or without direct intervention.
- To investigate reef design (location criteria and physical characteristics within a geographical variant context) with specific reference to determining surface area availability requirements.

Description of work (max. 1500 characters/350 words)

Mesocosm studies will be employed in order to test many of the theoretical assumptions relating to biofilter deployment. The use of mesocosms in the context of environmental impact assessment is an established methodology. The mesocosms will be established in tank-based facilities and will be representative of the sea bed types. Organic enrichment can be simulated using partially decomposed feed stuffs. A range of biofilter models (to represent differing designs and surface areas) will be introduced to the mesocosms and the performance will be assessed primarily through water column sampling and analysis of nitrate and ammonia levels, and the relative levels of aerobic degradation in the organic matter. Using these methods of assessment, an experimental matrix will be performed testing variables of organic loading, biofilter design and physico-chemical fluctuation (temperature and salinity changes) on biofilter performance. In addition to measuring direct performance, the mesocosm experiments will also be used to assess or estimate the rates of recovery (where applicable). Even if a biofilter receives too much organic material to function effectively, the rate of recovery for the same area of seabed may be accelerated in the presence of biofilters.

Deliverables (Max. 900 characters/200 words)

- Experimental data on design and performance that can be utilized in the modelling (WP02) and the field deployment (WP04) components of the project.
- Estimates of acceptable loading rates for each design will be obtained that will have direct relevance to farm husbandry practices.

Milestones and expected results (max. 900 characters/200 words)

This work package contains 2 milestones. The first (Milestone 3) is the to deliver fully-tested biofilter design criteria to work package 4 (WP04). These criteria will either drive proposed biofilter deployments or assist to alter existing deployments. The second milestone (Milestone 4) will be a matrix of organic loading regimes within which the performance of biofilters is not impaired.

The expected results are the satisfactory attainment of the work package milestones, the necessary data on which to base proposed biofilter field deployments or modify existing deployments (either in design or placement location), estimates of acceptable loading rates, data relating to recovery dynamics and supporting publications (academic papers and technical reports)

Work package number:	WP04
Start date or starting event:	3
No of partner responsible:	2
No of other partners involved:	1, 2, 3, 4, 5, 7, 8
Person months per partner: *(i.e. those charged to the project)*	
• Partner 2 (co-ordinator)	34.0
• Partner 1	18.0
• Partner 3	30.0
• Partner 4	82.0
• Partner 5	42.0
• Partner 7	6.5
• Partner 8	28.0

Objectives (max. 900 characters/200 words)

- To establish and verify field measurement criteria that will input into the required model verifications
- To undertake experimental biofilter deployments in the field situation
- To quantify the effects of biofilter deployment through field measurements of energy and nutrient fluxes
- To undertake detailed pre- and post-deployment hydrographical profiles for model validation purpose
- To record and quantify the rates and masses of biological settlement/accumulation on the biofilters.
- To quantify bioaccumulation within developing biological communities in terms both of pollutant uptake and nutrient accumulation.
- To investigate the fallowing dynamics of field-deployed biofilters.

Description of work (max. 1500 characters/350 words)

The fieldwork component of the programme will include the field deployment of biofilters in association with existing mariculture concerns. Some partners have already undertaken test deployments in preliminary studies. Deployments will be either under sea cages and/or placed in close proximity. All deployments will be replicated at least. The efficiency of the biofilters as a means of retaining particulate and soluble wastes will be determined through the analysis of fixed carbon, nitrogen and phosphorous on the filters, carried out over a range of temporal scales to infer performance. An additional indicator of performance will be the rate and turnover of fouling biomass accumulation. This will be measured through simple biomass change per unit area per unit time estimates and through established underwater respirometry techniques.

Sediment geochemistry and the structure of benthic communities provide a valuable means for quantifying the degree of organic enrichment. Therefore an additional method of assessing biofilter efficiency will be the measurement of temporal change in the benthic communities, in and around the biofilter deployments. Sediment profiling will be used to detect community response to benthic enrichment and the anticipated recovery period through the identification of changes in geochemical variables and the univariate and multivariate analyses of the macro- and meio-fauna. Changes in hydrography, affected by the physical introduction of additional man-made structures may be causative of other detectable changes. Hydrographical surveys will therefore be an essential component of this work package.

Deliverables (Max. 900 characters/200 words)

- The field deployment of biofilters in association with mariculture concerns
- A detailed assessment of field performance measured through energy/nutrient fluxes, hydrographical profiling, biological settlement and bioaccumulation
- An assessment of fallowing dynamics
- Collation of data for model validation

Milestones and expected results (max. 900 characters/200 words)

There are three milestones to be attained in this work package. The first is the deployment of bioifilters in association with mariculture on which to base the field deployment research (Milestone 5). The second milestone will be the delivery of complete data sets relating to the biological, biogeochemical and hydrological performance of the field deployments (Milestone 6). The final milestone is the environmental impact model revised in accordance with the field performance data (Milestone 2).

The expected results will be based on the satisfactory attainment of the work package milestones. This work package will result in the deployment of biofilters in the field, data sets relating to the performance of biofilters in a field situation and a field-validated revision of existing environmental impact models. Results will also be measurable through the publication of related information (academic papers and technical reports).

Work package number:	WP05
Start date or starting event:	0
No of partner responsible:	6
No of other partners involved:	1, 3, 4, 5
Person months per partner: *(i.e. those charged to the project)*	
• Partner 6 (co-ordinator)	12.0
• Partner 1	1.5
• Partner 3	2.0
• Partner 4	4.0
• Partner 5	4.0

Objectives (max. 900 characters/200 words)

- To produce legal and management guidance for regulatory bodies within the partner countries in relation to the use of hard artificial substrate as a biofilter for the mitigation of the environmental effects of aquaculture.
- To undertake a pan-European and global review of legal frameworks aimed at extrapolating the guidance to the multinational (particularly pan-European) level.
- To evaluate the transferability of legal models within the European context
- To develop an analytical tool within the framework of comparative legal analysis

Description of work (max. 1500 characters/350 words)

This work package will initially involve a desk-based review of the literature, the identification and collation of appropriate legal materials and the clarification of the appropriate frameworks of analysis. This will include pertinent materials within the fields of law governing, inter alia, marine aquaculture, marine environmental management, coastal planning and management, property and use rights, fisheries management and artificial reef deployment. The literature review will also cover frameworks of analysis, notably comparative legal analysis. The partners and external translation services will be instrumental in the translation of materials for use in the analytical process. The sourcing and preliminary review of secondary sources and primary legal documents will be followed by contacts and interviews with government agencies responsible for the regulation of the industry to establish the mode of implementation and the administrative procedures undertaken within the regulatory process. This will be used to elaborate on and identify the regulatory regime in practice. For the case study/ partner countries this will be supplemented by the identification of the mandates, objectives and priorities of the various stakeholder groups, both governmental and non-governmental, with respect to the deployment of artificial substrate as biofilters, to assist in the deployment of the experimental units during the project.

On the basis of the review, the necessary permits and authorisations for the deployment of the experimental units will be applied for, the various legal/regulatory and institutional models for the provision and governance of biofilters under current legal regimes within the partner countries and pan-European will be produced and recommendations for country and context specific modifications to the existing regimes to provide for their provision and governance. The transferability and applicability of the findings of the research and methodologies used will be assessed and the various deliverables produced.

Deliverables (Max. 900 characters/200 words)

- Targeted summaries of the findings of the work package
- A report summarising the findings
- Academic papers for publication in refereed journals
- Bibliographic database (PROCITE) of relevant literature and research in Europe and globally
- A compendium of legislation, manner of implementation for the context in question, institutional frameworks by country, and legal sources.

Milestones and expected results (max. 900 characters/200 words)

In combination with the provision of scientific evidence needed, the successful issue of permits and authorisations for the deployment of the experimental biofiltration units (Milestone 5).

The completion of the legal review, the identification of a typological classification of legal models and the isolation of modifications necessary and feasible within the constraints of existing legal regimes and political agendas, for the deployment of biofilters in both the case study/partner countries and elsewhere in Europe (Milestone 1).

Work package number:	WP06
Start date or starting event:	25
No of partner responsible:	6
No of other partners involved:	1, 2, 3, 4
Person months per partner: *(i.e. those charged to the project)*	
• Partner 6 (co-ordinator)	16.0
• Partner 1	1.5
• Partner 2	1.0
• Partner 3	1.0
• Partner 4	2.0

Objectives (max. 900 characters/200 words)

- To assess the external economic costs caused by the environmental impact of intensive mariculture
- To compare the net economic benefits of mitigating this environmental damage using a range of technically feasible options, including hard substrates

Description of work (max. 1500 characters/350 words)

This work package will involve a desk-based review of the literature on the environmental impacts of aquaculture and the economic externalities which these engender. The review will be accompanied by an empirical economic appraisal of the effects of hard substrate deployment in mariculture, employing two major approaches: (i) C*ost-effectiveness analysis*. This will be undertaken in order to determine the least-cost way of achieving a measurable reduction in the environmental damage caused by cage aquaculture, using in the first instance a biological or physical performance indicator. (e.g. a reduction in BOD by x%). The purpose of this analysis will be to compare the pollution prevention costs (PPC) of hard substrates against other technically feasible options. (ii) C*ost-benefit analysis*. This will involve an economic evaluation of both the monetary benefits and the costs of different options for offsetting the adverse environmental impacts of intensive mariculture. In terms of data requirements this second approach is the more challenging, since many of the benefits of improved environmental quality do not necessarily have a clearly defined market price against which to measure their worth to society. Fortunately, methodologies have now been developed to deal with this problem, the two which are applicable in this context for measuring the economic value of biofilter deployment being (a) *productivity-based methods* and (b) *preference-based methods.* Data for (a) will be derived from the results of the other work packages (e.g. in terms of a knowledge of the physical relationship between environmental quality change and fish catches) plus information on the economic value of these changes based on market or surrogate prices. Data for (b) will come from two sources: firstly, a contingent valuation survey in order to assess public willingness to pay for measures that would result in reduced pollution damage and improved water quality; secondly, a multi-attribute utility survey to assess public preferences and trade-offs between different dimensions of the pollution-reduction problem.

Deliverables (Max. 900 characters/200 words)

- A workshop report containing (i) a literature review (ii) summarising the methodology and results of the investigation
- Academic papers for publication in refereed journals
- Paper for presentation at the Annual Conference of the European Association of Fisheries Economists

Milestones and expected results (max. 900 characters/200 words)

The principal milestones will be empirical estimates of the economic costs and benefits associated with the deployment of hard substrates adjacent to intensive mariculture systems Milestone 7). Sensitivity analysis will show in quantitative terms the effect of changes in key variables on the net benefits of the project.

The results of the work will: (i) provide an analytical framework for measuring the external costs and economic impacts of intensive mariculture (ii) facilitate a comparison between the pollution damage costs caused by cage aquaculture with the pollution prevention costs (using biofilters or other solutions).